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Control of Air Emissions from Molybdenum Roasting. Volume 1 Emissions Characterization and Particulate Control

Molycorp, Inc., Washington, PA

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

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16. ABSTRACT

The primary objective of this project was to evaluate a baghouse employing Teflon® coated fabric bags for particulate recovery and control. This system was of great interest because of the corrosion resistance of Teflon® coated fabric filters and this unique application in the nonferrous metals industry. The Molycorp, Inc. operates the plant at its facility in Washington, Pennsylvania. The plant consists of two multi-level hearth furnaces, a high temperature baghouse and a water quench scrubber. Molybdenum disulfide is oxidized to molybdenum trioxide product and sulfur dioxide.

Removal efficiencies of the baghouse and quench-scrubber for heavy metal compounds are 98.2 and 89% respectively. The baghouse removal efficiency of 98.2% is based on tests performed on September 15 and 16, 1979. All the other data were measured during the June 1979 sampling effort. Sulfate contributions to the grain loadings are 0.4% at the roaster exit (600°F), 17% at the baghouse exit (450°F), and 91% at the quench scrubber exit (gas heated to 250°F according to EPA Method 5). Organic material does not contribute significantly to the quench scrubber exit grain loading.

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VOLUME I
EMISSIONS CHARACTERIZATION AND PARTICULATE CONTROL

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollution impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This document is one of a series of three reports resulting from a program to define the emissions control problems and explore applicable systems to control emissions from a molybdenum roaster. The program was jointly sponsored by Molycorp, Inc. and the Industrial Environmental Research Laboratory - Cincinnati to: (1) determine the capabilities of a unique fabric filtration system using Teflon® coated bags in a hot, corrosive atmosphere for particulate and trace element control and (2) to explore the feasibility of a variety of weak SO_2 control systems for application to the moly roaster and potentially to other smelter weak SO_2 off-gases.

David G. Stephan
Director
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ABSTRACT

The primary objective of this project was to evaluate a baghouse employing Teflon® coated fabric bags for particulate recovery and control. This system was of great interest because of the corrosion resistance of Teflon® coated fabric filters and this unique application in the nonferrous metals industry. The Molycorp, Inc. operates the plant at its facility in Washington, Pennsylvania. The plant consists of two multi-level hearth furnances, a high temperature baghouse and a water quench scrubber. Molybdenum disulfide is oxidized to molybdenum trioxide product and sulfur dioxide.

Removal efficiencies of the baghouse and quench-scrubber for heavy metal compounds are 98.2 and 89% respectively. The baghouse removal efficiency of 98.2% is based on tests performed on September 15 and 16, 1979. All the other data were measured during the June 1979 sampling effort. Sulfate contributions to the grain loadings are 0.4% at the roaster exit (600°F), 17% at the baghouse exit (450°F), and 91% at the quench scrubber exit (gas heated to 250°F according to EPA Method 5). Organic material does not contribute significantly to the quench scrubber exit grain loading.

One roaster (1800 lb/hr MoS_2 feed) produces 14,000 scfm stack gas. The main discharges to the atmosphere were:

- 1060 lb/hr Sulfur Dioxide
- 4 lb/hr Particulates Plus Sulfates
- 0.01 lb/hr Molybdenum
- 0.008 lb/hr Selenium
- 0.015 lb/hr Lead
- 0.007 lb/hr Iron
- 0.015 lb/hr Organic Material

A bench scale wet electrostatic precipitator completely removed the mist which presently forms the plume.

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SECTION 1

SUMMARY

The Molycorp, Inc. operates two multi-level hearth roasters at its facility in Washington, Pennsylvania. The plant processes 10 million pounds of molybdenum per year. In the roasting process molybdenum disulfide concentrate is oxidized by air to molybdenum trioxide and sulfur dioxide.

Particulate control is achieved by a baghouse, followed by a spray cooler and a packed bed. The water used is recirculated with a blow down. The baghouse employs Teflon® coated fabric filter bags, a unique application in the nonferrous industry. Primary interest was in determining the control efficiency of this baghouse for particulate and trace metals as a clean-up system prior to atmospheric discharge or a SO_2 control system.

The sampling and analysis effort described in this report was aimed toward the characterization of:

- the roasters,
- the high temperature baghouse,
- the spray scrubber - packed bed clean-up facility, and
- the flue gas.

The characterization comprised chemical analyses of all streams, flow rate measurements, grain loading determinations, particle size distribution measurements and baghouse performance studies under different operating conditions. Spark Source Mass Spectrometry (SSMS) was used to semiquantitatively analyze the samples. From these results, 15 elements were selected for quantitative determination. The selection was based on concentration level, volatility, and toxicity. The elements investigated more fully are:

Arsenic	Bismuth	Nickel
Lead	Antimony	Copper
Molybdenum	Cadmium	Manganese
Mercury	Silver	Iron
Selenium	Zinc	Rhenium

The quantitative analytical results were combined with the total mass flow in each individual stream to derive an elemental flow rate. These data finally were used to establish material balances around the roaster and the baghouse.

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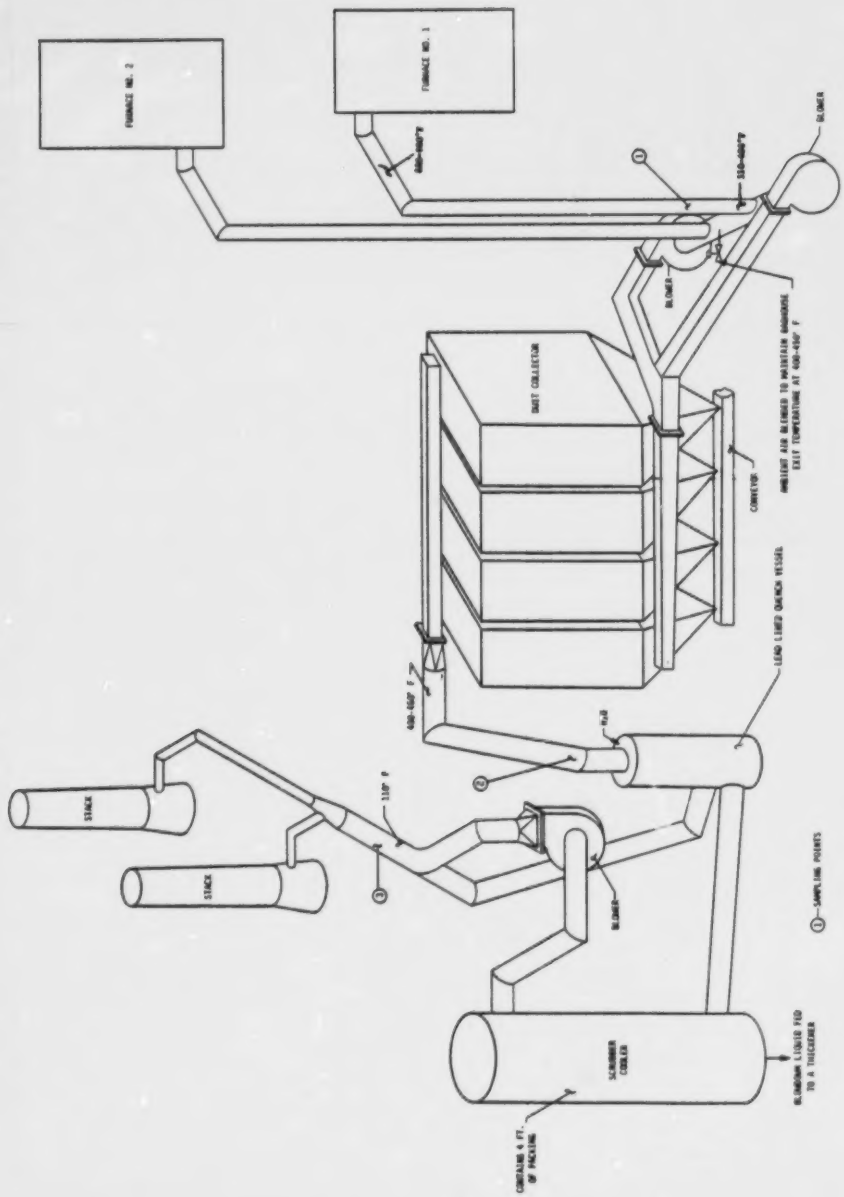

Figure 1. Dust Collection System at Molycorp

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Roaster Operation

During the sampling effort (June-23-78) only one roaster was operating. The feed rate was 1800 lb/hr MoS_2 consisting of a mixture of Questa ore (1650 lb/hr) and baghouse recycle dust (150 lb/hr). The exit gas flow was 8500 scfm (60°F, 29.9" Hg) with an average grain loading of 4.68 grains/scf and a SO_2 concentration of 13,000 ppm (v/v). A molybdenum trioxide production rate of 1345 lb/hr was calculated.

The analytical results for the roaster stream can be summarized as follows:

- Semiquantitative survey analyses by Spark Source Mass Spectrometry for 73 elements indicate that Twin Buttes and Questa concentrates show concentrations in the low ppm range for most heavy metals. Exceptions are:

Lead	Iron
Zinc	Manganese
Copper	

- Twin Buttes ore is high in copper (24,000 ppm versus 1000 ppm in Questa ore).

- Questa ore shows a high lead concentration (4300 ppm versus 930 ppm in Twin Buttes ore).

- Volatilization of selenium and mercury is indicated during the roasting process.

  Hg in feed: 2.3×10^{-4} lb/hr

  Hg in product: $.3 \times 10^{-4}$ lb/hr

  Se in feed: .15 lb/hr

  Se in product: .003 lb/hr

- Analytical data and flow determinations were checked by material balance for 15 elements. The closure is good for:

Lead	Silver
Molybdenum	Zinc
Mercury	Copper
Bismuth	Manganese
Antimony	Iron
Cadmium	

  The rhenium concentration was below the detection limit. Marginal closures were found for arsenic and selenium. The balance for nickel does not close. The reason is not obvious.

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Baghouse Balance

Sampling to establish a baghouse balance was done simultaneously with the roaster sampling. The following baseline conditions were measured:

Flow in: 8500 scfm
Flow out: 13100 scfm
Dust collection rate in baghouse: 272 lb/hr (June), 219 lb/hr (September)
Grain loading in: 4.68 grains/scf in June, 4.51 in September
Grain loading out: 0.040 grains/scf in September
Collection efficiency 98.2% (corrected for cooling air dilution)

The chemical analysis of all ingoing and outgoing streams showed the following:

- The element distribution of the dust collected in the baghouse is similar to that of the ore. The main crystalline phase is MoS_2.

- Most of the mercury and a large amount of the selenium are not retained in the baghouse.

- Good material balance closure was found for:

Arsenic	Antimony
Lead	Cadmium
Molybdenum	Silver
Mercury	Zinc
Bismuth	Manganese
Iron	

Difficulties were encountered in the balance closure for selenium, copper and nickel.

Grain loadings at the baghouse inlet and outlet determined in June were repeated in September. The June values were too high due to broken bags. See appendix for a detailed summary of the September values.

Quench Scrubber Characterization

The samples for the characterization of the Quench Scrubber were collected on June-21-78. The following base line parameters were measured:

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Roaster Feed:	1295 lb/hr Questa Ore
	159 lb/hr Twin Buttes Ore
	346 lb/hr Baghouse Recycle Dust
Inlet Gas Flow:	12200 scfm
Outlet Gas Flow:	14400 scfm
Inlet Grain Loading:	.98 grains/scf
Outlet Grain Loading:	.23 grains/scf

The water pickup was calculated from the water content at the inlet and outlet gas streams to be 5 gallons/min. Part of the grain loading in both inlet and outlet gas streams was due to sulfuric acid mist condensation. Sulfate formation contributed .17 grains/scf at the outlet.

The analytical findings point to the following conclusions:

- 90% of the mercury escaping the baghouse is retained in the quench scrubber.
- 50% selenium removal is achieved.
- The collection efficiency calculated from the elemental flow rates at inlet and outlet is 89%.
- Major discharges to the atmosphere are:
  - 28 lbs/hr solids containing large amounts of sulfates
  - 1060 lbs/hr SO_2
- Heavy metal discharge with the flue gas amounts to:

0.1 lb/hr Molybdenum	0.007 lb/hr Iron
0.08 lb/hr Selenium	0.015 lb/hr Organic Material
0.015 lb/hr Lead	

Organic Compounds in Plant Streams

The plume at Molycorp's facility was attributed by some earlier investigators to the discharge of organic material introduced by flotation agents. Extractions of selected solids, liquids and filters were, therefore, investigated by gas chromatography using a flame ionization detector. The results of the semiquantitative analyses show the following:

- Discharge rate with flue gas: 0.0151b/hr
- Quench water inlet: 0.045 lb/hr
- Quench water blow down: 0.052 lb/hr

- Ore feed: 0.1 lb/hr
- Baghouse recycle dust feed: 0.0001 lb/hr

The discharge of 0.015 lb/hr organic material cannot be the cause of the plume formation.

Sulfate Contribution to Grain Loading Measurements

The high oxygen, high SO_2 concentration of the roaster off-gases favors the formation of SO_3 as the flue gas cools. The SO_3 reacts with solids to form sulfates and with water vapor to form sulfuric acid mist. This increases the grain loading results as the gas temperature decreases. Acid dew points are 309°F at the roaster outlet, and 269°F at the baghouse outlet.

Grain loading determinations showed a particulate concentration at the roaster exit of 4.51 grains/scf. Analysis of the filter for sulfate indicated a sulfate contribution of 0.4%. An average grain loading of 0.040 grains/scf was measured at the baghouse exit. Sulfate contribution accounted for 17% of the particulate matter. Water droplets and acid mist were present in the quench-scrubber exit gases. Water had to be evaporated in order to determine a grain loading. The EPA method 5 was used. Contributions of sulfuric acid mist accounted for 50%, 35%, 74% and 91% at sampling temperatures of 380°F, 365°F, 300°F and 250°F, respectively. These results point to sulfuric acid mist as the cause of the plume formation. The mist was completely removed in a bench scale wet electrostatic precipitator.

Based upon this information, it was concluded that the sulfate particulate and sulfuric acid mist, not organics, contributed most to the grain loading observed in the stack gas.

Baghouse Efficiency and Particle Sizing Studies

Baghouse efficiency was found to be 98.2%. Particle sizing during June showed a very high percentage of large (>2 μm) material penetrating the baghouse. This is indicative of unreplaced broken bags. The baghouse efficiency determination was repeated therefore in September. (See Appendix B for details).

TABLE 1. SUMMARY OF SAMPLING EFFORT JUNE-1978

Date	Site[1]		Sample	Procedure	Comments
Roaster Balance					
6/23	1	2	Grain Loadings	EPA-5	
		1	SO_2 - SO_3	EPA-8	
		1	Vapor Phase Trace Elements	Acid/Base Train	
		2	Total Elements	Radian WEP	
	4		Questa Ore Bin 6	24 Hr Composite	
			Questa Ore Bin	24 Hr Composite	
	5		Baghouse Recycle Dust	24 Hr Composite	
	8		Product Molybdenum Oxide	24 Hr Composite	
Baghouse Balance					
6/22	2	2	Grain Loadings	EPA-5	
		1	Vapor Phase Trace Elements	EPA-8	
		1	Particle Size	In-stack Andersen	
		1	Baghouse Recycle Dust	24 Hr Composite	
	5	2	Grain Loadings	EPA-5	
6/23	1	1	SO_2 - SO_3	EPA-8	
		1	Vapor Phase Trace Element	Acid/Base Train	
		2	Total Elements	Radian WEP	
		1	Grain Loading	EPA-5	
	2	1	SO_2 - SO_3	EPA-8	
		1	Total Elements	Radian WEP	
	5	1	Baghouse Dust	24 Hr. Composite	
6/24	1	1	Particle Size	In-stack Brinks	
Quench Scrubber Efficiency					
6/20	3	2	Grain Loadings	EPA-5	Filters at 380°F
		2	SO_2 - SO_3	EPA-8	
		2	Particle Sizings	Out-of-Stack Andersen	Sampler at 300°F
	6	1	Quench Scrubber	Injection Water	Grab Sample & Flow Rate
	7	1	Quench Scrubber	Blow Down Water	Grab Sample & Flow Rate
6/21	2	2	Grain Loadings	EPA-5	In-Stack Filter
		2	SO_2 - SO_3	EPA-8	
		1	Total Elements	Radian WEP	
	3	1	Grain Loading	EPA-5	Filter at 300°F
		1	SO_2 - SO_3	EPA-8	
		2	Total Elements	Radian WEP	
6/22	2	1	Grain Loading	EPA-5	In-Stack Filter
		1	Vapor Phase Trace Elements	Acid/Base Train	
		1	Total Elements	Radian WEP	
		1	Particle	In-Stack Andersen	
	3	1	Grain Loading	EPA-5	Filter at 250°F
		1	Vapor Phase Trace Elements	Acid/Base Train	
	6	1	Quench Injection Water	Grab Sample & Flow Rate	
	7	1	Quench Blow Down Water	Grab Sample & Flow Rate	
Baghouse Efficiency Studies					
6/22	2	1	Grain Loading	EPA-5	
		1	Particle Size	In-Stack Andersen	
6/23	1	2	Grain Loadings	EPA-5	
		1	SO_2 - SO_3	EPA-8	
	2	1	Grain Loading	EPA-5	
		1	SO_2 - SO_3	EPA-8	
6/24	1	1	Particle Size	In-Stack Brinks	
6/26	1	2	Grain Loadings	EPA-5	
		2	SO_2 - SO_3	EPA-8	
		1	Particle Size	In-Stack Brinks	
	2	2	Grain Loadings	EPA-5	
		2	SO_2 - SO_3	EPA-8	
		3	Particle Sizings	In-Stack Andersen	
6/27	1	1	Grain Loading	EPA-5	
		1	SO_2 - SO_3	EPA-8	
		1	Particle Size	In-Stack Brinks	
	2	1	Grain Loading	EPA-5	
		1	SO_2 - SO_3	EPA-8	
			Particle Size	In-Stack Andersen	
Atmospheric Emissions					
6/20	3	1	Grain Loading SO_4^{-2} as H_2SO_4 Organics	EPA-5	Dual Filters at 380°F Vertical Traverse
		1	Grain Loading SO_4^{-2} as H_2SO_4 Organics	EPA-5	Dual Filters at 365°F Horizontal Traverse
		1	SO_2 - SO_3	EPA-8	380°F
		1	SO_2 - SO_3	EPA-8	365°F
6/21	2	2	Grain Loadings SO_4^{-2} as H_2SO_4	EPA-5	Dual In-Stack Filters Plus Out of Stack Filter at 300°F
		2	SO_2 - SO_3	EPA-8	
	3	1	Grain Loading SO_4^{-2} as H_2SO_4 Organics	EPA-5	Dual Filters at 300°F
		1	SO_2 - SO_3	EPA-8	
6/22	3	1	Grain Loading SO_4^{-2} as H_2SO_4 Organics	EPA-5	Dual Filters at 250°F

[1]Sample Site
1 Between Roaster and Baghouse
2 Between Baghouse and Quench Scrubber
3 After Quench Scrubber
4 Concentrate Feed at Feeder
5 Baghouse Dust Feed at Feeder
6 Recycle Pump By-Pass
7 Quench Scrubber Blow Down Drain
8 Product Stream From Roaster

TABLE 2. SUMMARY OF MEASUREMENT RESULTS

Experimental Results		June-20	June-21	June-22	June-23	June-26	June-27
1. Ore Feed Rates							
• Quanta 6 lb/hr		ND*	1295	1470	1650	ND	ND
• Twin Buttes lb/hr		ND	159	180	0	ND	ND
• Baghouse Dust Recycle lb/hr		ND	346	150	150	ND	ND
TOTAL FEED RATE		ND	1800	1800	1800	ND	ND
2. MoO_3 Production Rate (lb/hr)		ND	1430	1450	1380	ND	ND
3. Gas Flow							
• Roaster Exit acfm		ND	ND	ND	8400	8150	9200
• Baghouse Exit acfm		ND	11950	11500	13100	12650	13000
• Stack Discharge acfm		13600	14400	14700	ND	ND	ND
4. Grain Loading							
Was repeated in September due to broken bags in June. (See Appendix H)							
5. Gas Composition							
• Roaster Outlet -	SO_2 ppm	ND	ND	ND	13500	13550	12700
	SO_3 ppm	ND	ND	ND	90	87	114
	H_2O%	ND	ND	ND	3.5	4.8	4.4
• Baghouse Outlet -	SO_2 ppm	ND	6100	ND	4560	7360	5980
	SO_3 ppm	ND	20	ND	7	20	13
	H_2O%	ND	3.3	3.2	2.8	4.3	3.5
• Stack Discharge -	SO_2 ppm	6500	7360	ND	ND	ND	ND
	SO_3 ppm	46	18	ND	ND	ND	ND
	H_2O%	8.8	8.9	8.9	ND	ND	ND
6. Baghouse Dust Catch lb/hr		ND	219	302	275	ND	ND
7. Intake Quench Water gal/min		ND	32	35	ND	ND	ND
8. Quench Water Blowdown gal/min		ND	26.6	30	31.9	ND	ND
9. Particle Size Distribution (% less than indicated size)[1]					(June-24)		
• Brinks Roaster Exit							
- Cyclone catch	<2.1 μm				24	21	26
- Plate 1	<1.2				17	16	20
- Plate 2	<0.50				12	12	15
- Plate 3	<0.35				8.5	9.4	11
- Plate 4	<0.22				6.7	7.0	8.8
- Plate 5	<0.14				4.4	4.8	6.6
• Andersen Baghouse Exit							
Determined values invalid due to broken bags.							
• Andersen Stack							
- Plate 1	<8.0 μm	92	82				
- Plate 2	<7.4	87	65				
- Plate 3	<4.6	83	50				
- Plate 4	<3.1	81	38				
- Plate 5	<1.6	79	34				
- Plate 6	<0.88	77	13				
- Plate 7	<0.44	76	4				
- Plate 8	<0.23	71	0.2				
- Filter							

[1] Indicated size is average for runs at a given location.
[2] The cut sizes on this run were significantly different than the others taken at this location.
*ND = not determined

TABLE 3. SUMMARY OF QUANTITATIVE ANALYTICAL RESULTS

Sample Description	ROASTER BALANCE				BAGHOUSE BALANCE		SCRUBBER EFFICIENCY			
Element	Questa Ore ppm	Twin Buttes Ore ppm	MnO_2 Product ppm	WEP Site 1 June-23-78 µg/scf*	Baghouse Dust ppm	WEP Site 2 June-23-78 µg/scf*	WEP Site 3 June-21-78 µg/scf*	WEP Site 3 June-21-78 µg/scf*	Inlet Water µg/ml	Outlet Water µg/ml
Arsenic	12	9.9	19	15	48	1.67	1.40	.38	1.3	1.82
Lead	4300	980	4800	1780	6500	139	120	7.8	10.2	10.1
Molybdenum	470000	360000	540000	149000	490000	11500	11400	55	3040	3810
Mercury	.15	.15	.023	.22	.23	.11	.11	.016	.032	.061
Selenium	56	122	2.6	157	400	89	90	44	8.95	10.2
Bismuth	280	63	160	113	350	4.8	4.5	.22	1.51	3.67
Antimony	21	80	19	7.0	27	.59	.55	.03	.13	0.39
Cadmium	18	14	20	7.6	31	.70	.70	.16	.55	0.67
Silver	38	62	49	14.2	57	1.33	1.20	.39	<.05	<.05
Zinc	1500	240	1700	485	1900	45.3	45	.26	43.1	51.5
Nickel	96	26	59	8.4	55	.78	.75	.078	1.89	2.22
Copper	950	24000	1500	401	3700	19.3	19	.78	158	194
Manganese	730	840	890	197	770	14.0	13	.70	39	46
Iron	11800	32500	17000	3750	17800	31.4	31	3.9	850	1000
Rhenium	<10	<10	<10	<1	<10	<1	<1	<1	<1	<1

*µg/scf of gas sampled

TABLE 4. SUMMARY OF ELEMENTAL FLOW RATES IN ROASTER STREAMS

	ROASTER STREAMS 6-23				BAGHOUSE STREAMS 6-23			HUMIDIFIER - SCRUBBER STREAMS JUNE-21-78		
	Quartz Feed (1650 lb/hr) lb/hr	Dust Feed (150 lb/hr) lb/hr	H_2O_2 Product (1345 lb/hr) lb/hr	Roaster Dust (341 lb/hr) lb/hr	Baghouse Dust (272 lb/hr) lb/hr	Baghouse (1) Gas & Dust (46 lb/hr) lb/hr	Baghouse (2) Gas & Dust (103 lb/hr) lb/hr	Quench Off-Gases (16 lb/hr) lb/hr	Quench Water Inlet (31 gal/min) ug/g	Quench Water Outlet 26 gal/min ug/g
Arsenic	.020	.007	.025	.017	.013	.003	.003	.0007	.020	.022
Lead	7.1	.90	6.44	2.00	1.64	.24	.21	.015	.17	.134
Molybdenum	780	74	725	158	134	20	19.8	.101	48	51
Mercury	2×10^{-4}	$.3 \times 10^{-4}$	$.3 \times 10^{-4}$	2.5×10^{-4}	$.6 \times 10^{-4}$	2.0×10^{-4}	2.0×10^{-4}	$.3 \times 10^{-4}$	5×10^{-4}	8×10^{-4}
Selenium	.092	.060	.003	.18	.11	.16	.16	.08	.11	.14
Bismuth	.46	.05	.21	.13	.10	.006	.006	4×10^{-4}	.02	.05
Antimony	.035	.004	.025	.008	.007	.001	.001	$.6 \times 10^{-4}$	.005	.005
Cadmium	.030	.003	.027	.009	.006	.001	.001	3×10^{-4}	.008	.009
Silver	.063	.008	.066	.016	.014	.002	.002	7×10^{-4}	<.0008	<.0007
Zinc	2.48	.29	2.28	.55	.52	.08	.08	5×10^{-4}	.68	.685
Nickel	.16	.008	.079	.009	.015	.001	.001	$<1 \times 10^{-4}$	.03	.030
Copper	1.6	.56	2.0	.45	1.0	.03	.033	1.5×10^{-3}	2.5	2.6
Manganese	1.2	.12	1.19	.22	.21	.02	.023	1.3×10^{-3}	.62	.612
Iron	20	2.7	22.8	4.22	4.88	.05	.054	7.3×10^{-3}	13.2	13.3
Rhenium	<.02	<.002	<.01	<.3	<.003	<.005	<.005	<.0003	<1.3	<.04

(1) and (2) represent samples obtained from the baghouse off-gas stream.

TABLE 5. SUMMARY OF SURVEY ANALYSES BY SPARK SOURCE MASS SPECTROMETRY

Element	Twin Buttes Ore ppm	Questa Ore ppm	MoO_3 Product ppm	June 23 WEP Site 1 µg/scf	Baghouse Dust ppm	June 23 WEP Site 2 µg/scf*	June 21 WEP Site 2 µg/scf*	June 21 WEP Site 3 µg/scf*	Quench Water In µg/ml	Quench Water Out µg/ml
Uranium	8	15	20	7	10	-	.3	-	.1	1
Thorium	3	22	32	7	*17	-	.3	-	.2	3
Bismuth	90	40	77	29	300	.3	3	.04	.4	.1
Lead	430	>1000	>1000	>360	>1000	3	26	.2	4	.3
Thallium	1	7	11	3.5	7	-	.02	-	.01	.02
Mercury	NR	NR	-	NR	NR	NR	NR	NR	NR	NR
Gold	.2	-	<.2	-	<.1	-	-	-	-	<.04
Platinum	-	-	<.2	-	-	-	-	-	-	-
Iridium	-	-	-	-	-	-	-	-	-	-
Osmium	-	-	-	-	-	-	-	-	-	-
Rhenium	140	11	3	<.2	13	5	4	*3	.2	2
Tungsten	26	5	10	3.5	9	-	.4	-	.6	3
Tantalum	<.4	<2	-	-	<4	<.4	<.07	<.8	-	<.08
Hafnium	-	-	-	-	-	-	-	-	-	-
Lutetium	-	-	-	-	-	-	-	-	-	.02
Ytterbium	-	-	1	-	-	-	-	-	-	.1
Thulium	-	-	.2	-	-	-	-	-	-	.01
Erbium	.5	.9	.7	-	.5	-	-	-	.005	.1
Holmium	.6	1	1	-	.6	-	-	-	.008	.1
Dysprosium	*1	2	2	-	1	-	-	-	.02	.2
Terbium	.2	.4	.7	-	<.2	-	-	-	.004	.05
Gadolinium	.9	1	3	-	1	-	-	-	.02	.1
Europium	.5	.5	.9	.1	.5	-	-	-	.008	.1
Samarium	2	2	9	.7	2	-	.06	-	.1	.9
Neodymium	6	6	25	3.7	13	-	.2	-	.2	5
Praseodymium	*2	3	5	1.8	6	-	.1	-	.1	2
Cerium	14	12	32	21	30	.1	.4	.05	3	>10
Lanthanum	12	43	58	21	30	.06	.4	.07	8	>10
Barium	31	44	60	18	56	1	.4	.2	.02	.2
Cesium	3	1	1	3	2	-	.03	-	<.001	.02
Iodine	35	-	10	3.5	<5	-	.2	-	.01	.05
Tellurium	22	38	42	25	220	.7	.5	<.1	< 1	1
Antimony	41	72	78	14	91	.4	1	.04	.2	.2
Tin	26	19	51	1.8	47	.6	.6	.1	1	.2
Indium	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD

Continued

*µg/scf of gas sample
NR - Not reported
STD - Standard

TABLE 5. SUMMARY OF SURVEY ANALYSES BY SPARK SOURCE MASS SPECTROMETRY (Continued)

Element	Twin Buttes Ore ppm	Questa Ore ppm	MoO_3 Product ppm	June 23 WEP Site 1 µg/scf	Baghouse Dust ppm	June 23 WEP Site 2 µg/scf*	June 21 WEP Site 2 µg/scf*	June 21 WEP Site 3 µg/scf*	Quench Water In µg/ml	Quench Water Out µg/ml
Cadmium	170	67	330	25	85	.04	1	-	.7	.8
Silver	120	220	75	32	160	>.2	>.2	>.2	.08	.5
Palladium	-	-	-	-	-	-	-	-	-	-
Rhodium	-	-	-	-	-	-	-	-	-	-
40 Ruthenium	-	-	-	-	-	-	-	-	-	-
Molybdenum	>1000	>1000	>1000	>360	>1000	>95	>90	>90	>10	>10
Niobium	3	11	23	3.5	15	.04	.5	-	.3	1
Zirconium	19	27	29	1.4	19	.6	.2	.60	.1	1
Yttrium	17	14	16	2.5	17	.07	.2	-	.2	1
45 Strontium	47	33	24	7.1	83	.2	.6	.08	3	7
Rubidium	25	8	13	3.2	10	>.01	.2	>.01	.2	.3
Bromine	10	.8	4	.7	3	-	.04	.04	.02	.1
Selenium	290	110	7	2.1	480	5	9	9	2	>10
Arsenic	49	43	47	7.1	81	1	2	.9	1	.5
50 Germanium	7	1	1	1	7	.05	.2	>.04	.02	.1
Gallium	10	5	15	2.5	4	.02	.1	.03	.1	.4
Zinc	>1000	>1000	>1000	>360	>1000	3	27	*2	>10	>10
Copper	>1000	930	>1000	>360	>1000	6	90	.7	>10	>10
Nickel	210	210	75	14	48	>95	2	1	2	7
55 Cobalt	22	40	34	7	22	.7	1	.04	2	8
Iron	>1000	>1000	>1000	>360	>1000	50	>90	27	>10	>10
Manganese	>1000	>1000	>1000	290	>1000	2	8	.3	>10	>10
Chromium	6	24	52	3.5	6	1	.8	.3	1	>10
Vanadium	22	39	42	3.5	22	2	.5	.04	.5	1
60 Titanium	INT	INT	INT	INT	INT	INT	INT	INT	INT	INT
Scandium	3	12	3	.1	2	>.02	.1	>.03	.08	.7
Calcium	>1000	>1000	>1000	>360	>1000	>95	>90	>90	>10	>10
Pottassium	480	>1000	>1000	>360	>1000	10	62	27	>10	>10
Chlorine	13	8	42	-1	13	.09	.5	.1	.3	>10
65 Sulfur	>1000	>1000	>1000	>360	>1000	>95	>90	>90	>10	>10
Phosphorus	50	>1000	>1000	>360	670	7	27	36	>10	>10
Silicon	>1000	>1000	>1000	290	>1000	30	9	18	>10	>10
Aluminum	>120	200	>1000	70	>120	>20	>18	4	>2	>5
Magnesium	>120	>1000	>1000	>360	>1000	40	>90	9	>10	>10
70 Sodium	>300	20	>1000	>210	50	>30	44	18	>5	>10
Fluorine	>1000	~320	~160	~140	~140	~.3	3	~.2	~2	~3
Oxygen	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Carbon	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
75 Boron	2	3	5	.7	.7	.4	.1	>.01	2	6
Beryllium	-	-	-	1.4	-	-	-	-	-	-
Lithium	4	7	11	3.5	4	.07	.04	.01	.7	.8
Hydrogen	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

*µg/scf of gas sampled
NR - Not Reported
STD - Standard

SECTION 2

FACILITY DESCRIPTION

Figure 2 is a schematic flow diagram of the facility studied. Also shown are the sampling locations used by Radian. Ore concentrate is fed to the roasters and product molybdenum trioxide is recovered. Sulfur oxides, entrained dust, and other combustion gases are exhausted from the roaster, cooled with ambient dilution air, and routed to the baghouse. Recovered baghouse dust is recycled to the roaster. The cleaned gas stream is passed into a quench tower where it is cooled and washed, then to a packed tower demister. From there it is passed to the stacks and vented to the atmosphere. During the Radian sampling only one roaster was in operation.

Roaster

Molybdenum sulfide ore concentrates (MoS_2) are fed to a multi-hearth furnace where the molybdenum disulfide is oxidized to sulfur oxides and molybdenum trioxide (MoO_3). The overall reaction is highly exothermic liberating approximately 4900 Btu/lb of molybdenum converted from the sulfide to the trioxide. The reaction takes place in two steps:

$$MoS_2 + 3O_2 \rightarrow MoO_2 + 2SO_2 \qquad (4200 \text{ Btu/lb Mo})$$

$$MoO_2 + \tfrac{1}{2}O_2 \rightarrow MoO_3 \qquad (\ 700 \text{ Btu/lb Mo})$$

The molybdenum sulfide (molybdenite) concentrate contains water and flotation oil coming from the concentration process. This oil adds another 1900 Btu/lb molybdenum to the exothermic reaction.

Because of the eutectic formed by molybdenum sulfide, molybdenum dioxide, and molybdenum trioxide, very careful control of the temperatures within the roaster must be maintained. The multi-hearth roaster is comprised of 10 vertical beds. (See Figure 3). The ore concentrate, previously mixed with recycled baghouse dust, is dropped into the top hearth by a conveyor. A sweeper arm at each bed level moves the ore around the bed to a slot where it cascades down to the next lower bed. The oxide "clinker" is discharged at the bottom of the roaster to a crusher and then to a hopper. Air is drawn in at each bed or hearth level through a series of dampers, and is usually in ten fold excess over stoichiometric requirements. This is done to maintain temperatures. Natural gas burners are used at the bottom of the roaster for additional temperature control.

Four furnace zones are designated for purposes of temperature and product control. The first two hearths (and sometimes the third) make up the first

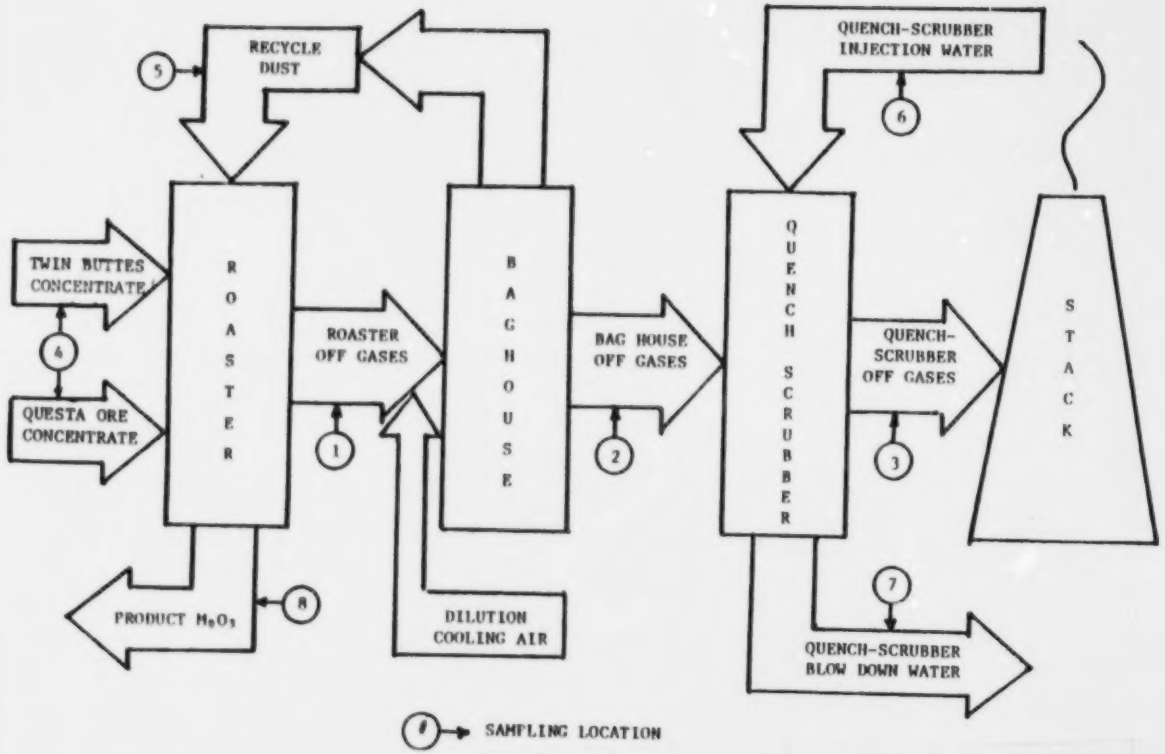

Figure 2. Schematic of material flows and sampling point locations.

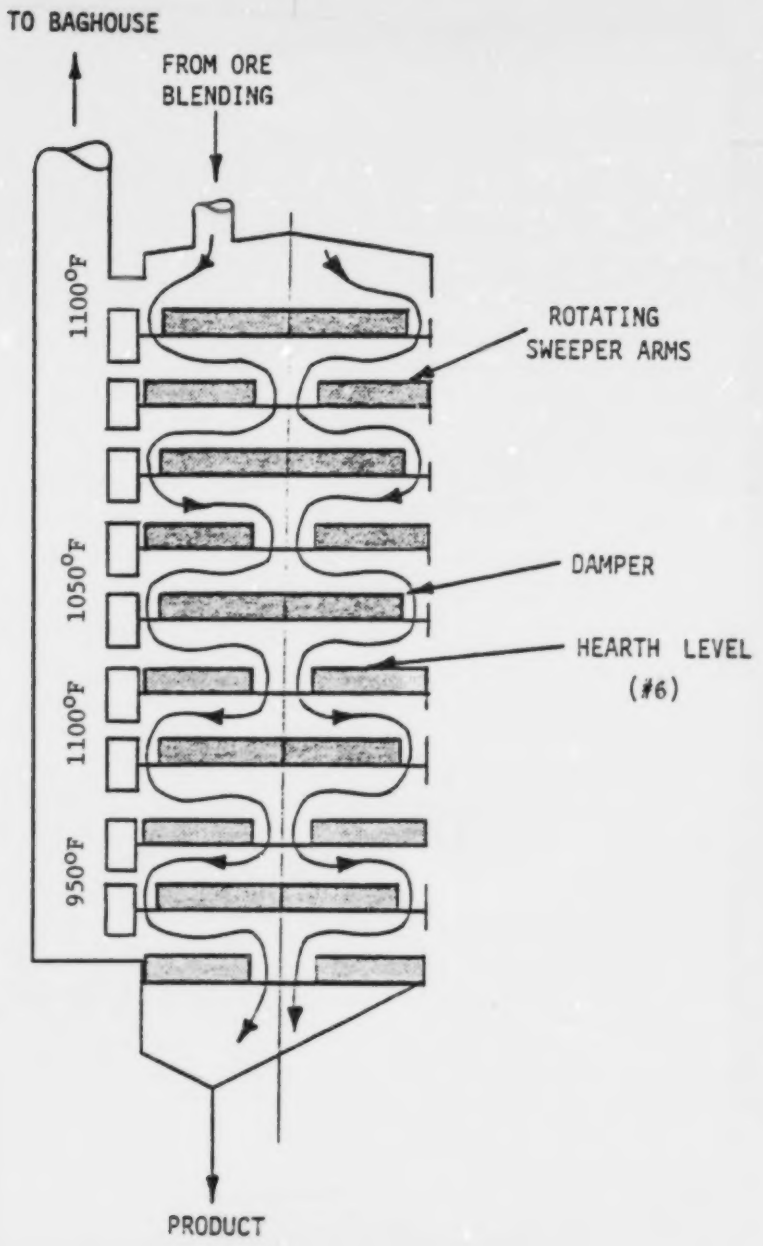

Figure 3. Schematic of Molycorp's multilevel hearth roaster.

zone in which the flotation oil vaporizes and burns (temperature ∿1100°F). Molybdenum sulfide is partly converted in this zone to the dioxide. The second zone (hearths 3 to 6) is where the conversion of the molybdenite to the dioxide (temp 1050°F) is completed. The proportion of trioxide remains low. The seventh and eigth hearth make up the third zone in which the dioxide is converted to the trioxide (temp ∿1100°F). In the fourth zone (hearths 9 and 10) the oxidation is completed (temp ∿950°F). Because 95% of the material has been converted by the time it enters this zone, supplemental heat is required. This is achieved with natural gas burners.

Off-gases are pulled out of the roaster through a manifold by a downstream fan. This gas is composed of excess air and sulfur oxides carrying entrained dust. The draft on the roaster is maintained with a damper system in conjunction with the fan. The draft at each hearth level is controlled with the individual dampers at that level.

As the ore concentrate cascades into the first hearth of the roaster, a large quantity of dust is entrained and swept out the exhaust. This is not observed at other hearth levels. The rest of the feed ignites and burns as it enters the roaster. The flame is not smokey and the retention time in the hearth area appears to be on the order of seconds.

Baghouse

The exhaust gases from the roaster are passed through a baghouse for dust recovery. A schematic of the baghouse is shown in Figure 4. It is designed to operate at temperatures between 400°F and 500°F. The gases exiting the roaster are between 800°F and 900°F and cool to about 600°F. Therefore, diluent air is drawn in ahead of the baghouse to cool the incoming gases.

The baghouse is composed of 4 separate compartments, each containing 264 bags. The bags are arranged in an 8 x 33 array, are 8 inches in diameter, and are 20 feet long. The cloth area is ∿11,000 ft^2/compartment. The bags are cleaned by periodic shaking, automatically controlled by timers. Current operating practice is to shake an individual compartment every hour. This allows the pressure drop across the given compartment to build to about 5 inches of water (three compartments in operation handling one roaster).

During shaking the compartment is cut off from the exhaust gas stream by a hydraulically operated flapper valve. The dust collected in the bags is dropped into a hopper beneath the compartment from which it is fed to a conveyor. The conveyor transports the material to a bin equipped with scales. The dust is then recycled to the roaster. The off-gases are collected in an overhead manifold and discharged to the quench scrubber system.

Quench Scrubber

The quench scrubber is a dual chamber system as shown in Figure 5. Gases from the baghouse enter the quench tower at approximately 380-400°F

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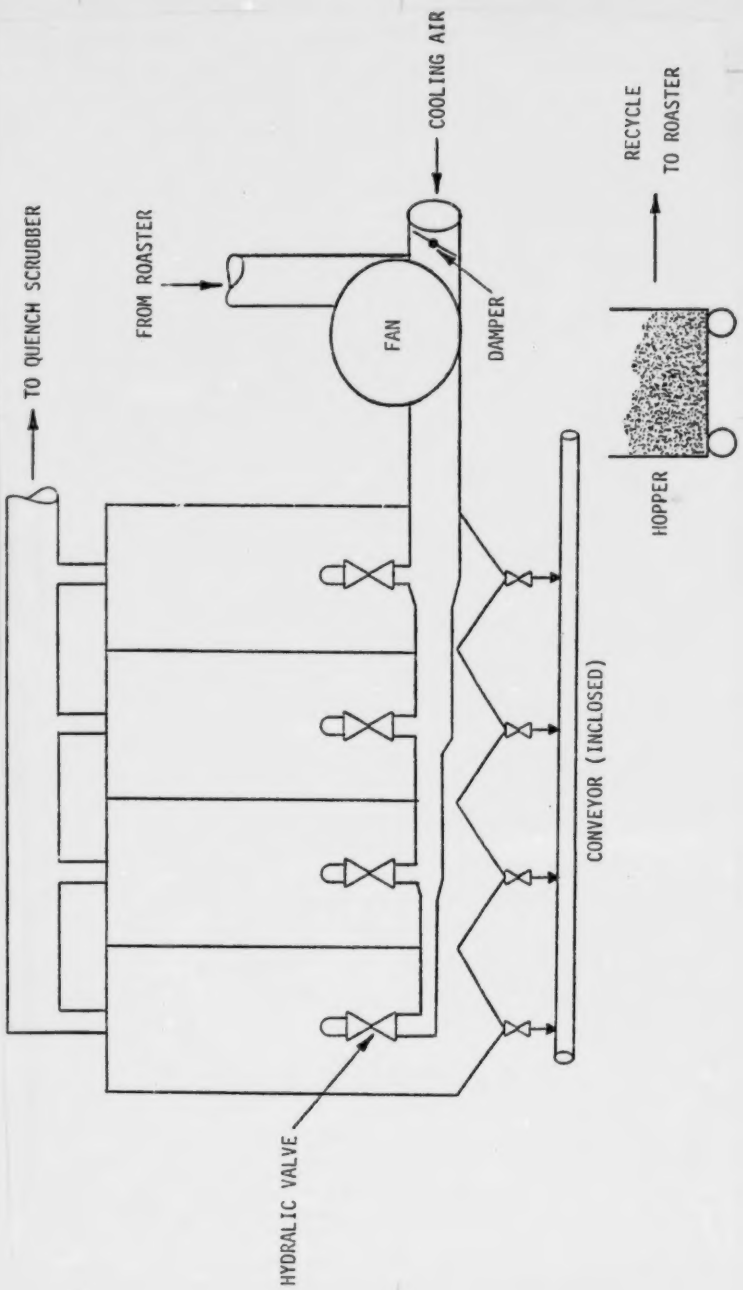

Figure 4. Schematic of baghouse at Molycorp's roasting facility.

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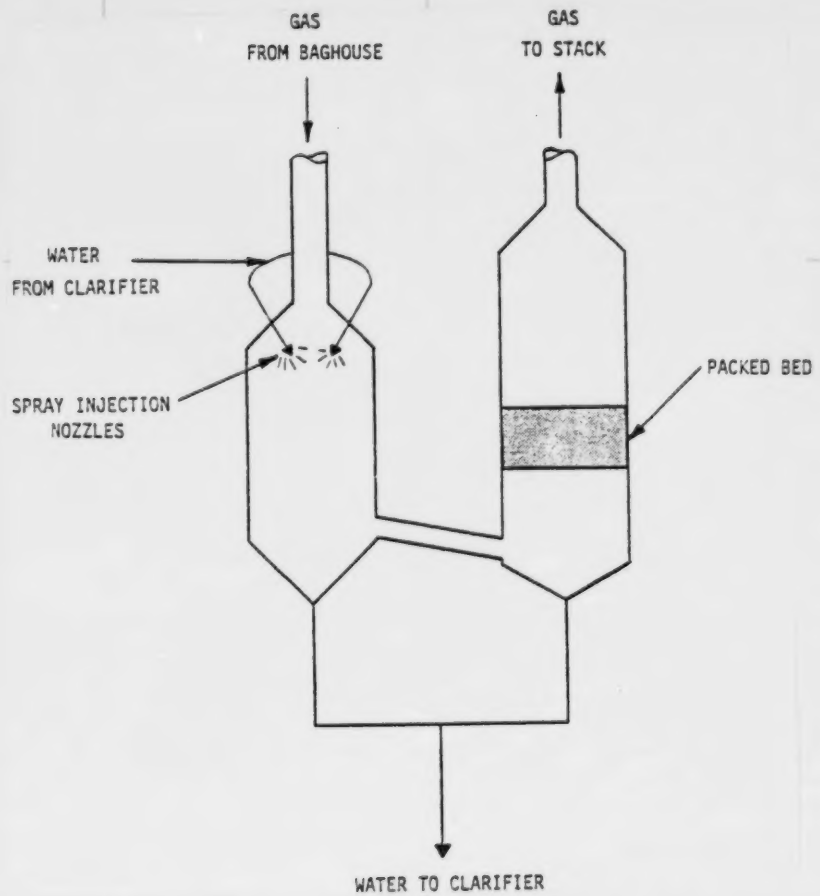

Figure 5. Spray tower - packed bed (spray scrubber) gas cleaning facility at Molycorp.

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and are cooled by spray evaporation to about 110°F. The gas enters the top of the quench tower, passes through the spray pattern, and exits the bottom. The gas then enters the scrubber (demister); the velocity slows by expansion, and the gas passes through a packed bed. A large volume chamber is above the packed bed to allow further "rain-out" of condensed water vapor.

The water for quenching is pumped from a clarifier tank, and after passing through the quench scrubber, returns to that tank. The retention time in the clarifier is on the order of days. The water receives no other treatment. Through its contact with sulfur oxides in the gas stream, the water builds up a very high acidity. Therefore, the quench tower is lead lined to avoid corrosion by the acidic quench water. The quench water is blue-black in color and highly acidic. This is true both for the incoming water and the return water. Although the solutions are opaque, there appears to be very few suspended solids.

Because of the high concentrations in the incoming and outgoing streams, material balances around this unit are subject to large errors. This results from the fact that there are small differences between large numbers.

Condensed water vapor is visible at the sample point between the quench scrubber and the stack. Thus, the collected moisture at this point will consist of both condensed water droplets and vapor. Vapor phase water content of this stream must be assumed to be saturated at the gas temperature.

The discharge plume is cool and saturated with water. Upon dissipation of the steam a gray haze remains.

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SECTION 3

SAMPLING TECHNIQUES

To meet the requirements of the testing program, several different types of sampling were conducted. The various sampling methodologies are described below. In most cases, standard methods were applied. Where variations from standard procedures were used, the departures are outlined.

Gases

Volume Flow Rates--

Gas stream velocities were measured with standard "S-type" pitots. Pressure differentials were read with magnehelic gauges. Temperatures were determined with chromel-alumel thermocouples using digital temperature indicator read-outs. Atmospheric pressure was determined with an aneroid barometer. Velocities and volumetric flow rates were calculated using EPA reference methods 1 and 2.

Gas Analysis for Dry Molecular Weight--

To determine dry molecular weight of the gas stream, grab samples were taken in aluminized Teflon® bags. Samples were analyzed on a Fisher Gas Partitioner with a thermoconductivity detector. The gas chromatograph uses a drying column which is followed by a fixed volume gas sampling loop. Values are calculated from curves generated with standard gases.

Moisture Content--

Moisture content of the gas streams was determined by the condensation weight method (EPA Method 4) for those streams above the moisture dew point temperature. A metered volume of gas is drawn through a series of impingers, the last containing silica gel. The impingers are immersed in an ice bath. The impinger weight gain minus the weight of sorbed SO_2 and SO_3 represents the water content of the sample volume. The volume percent is then calculated.

For the stream below dew point temperature, the moisture content was calculated as the saturation content at the given gas temperature.

Sulfur Oxides--

The sulfur oxide content of the gas stream was sampled using EPA reference method 8, but using a different analytical procedure. After passing through a filter, the gases are scrubbed in an impinger containing 80% v/v

isopropanol in water, then into two 6% H_2O_2 impingers in series. The total gas volume is metered. The first impinger is analyzed for sulfate and sulfite. The second and third impingers are analyzed for sulfate (SO_2 oxidizes to sulfate by peroxide). An ion exchange chromatograph was used for the quantitative sulfate determination.

Liquids

Grab Samples--

A 500 ml container was rinsed with the liquid, then filled to the brim, capped, sealed, and labeled. Temperature and pH readings on a second sample were taken at the same time. The pH readings were taken with a Leeds and Northrup portable single electrode pH meter. The instrument was calibrated against a standard buffer (pH 3) just prior to reading the sample.

Solids

Flow Rates--

Roaster feed rates and baghouse dust recovery rates were measured by plant personnel. An hourly record of the amount of each material fed to the roaster is kept by plant personnel. A shift record (8 hr) is kept of the amount of baghouse dust recovered. There is no equivalent record kept of product molybdenum oxide. This number was determined by material balance calculation.

Sampling--

During the testing period, approximately 490 lbs Questa ore, 60 lbs Twin Buttes ore, and 50 lbs baghouse dust were fed to the roaster at 20 minute intervals. From each material, approximately 100 grams were drawn at each interval. These samples were composited over a 24 hr period, blended, cut, and a fraction (approximately one kilogram) taken as sample. The sampling was carried out by the plant personnel using their standard procedures.

The product molybdenum oxide is sampled from the conveyor to the holding bin by an automatic screw sampler. A 24 hr composite was treated in the same manner as the feed material.

Particulates

Grain Loading--

Grain loadings were determined using EPA reference methods 5 and 17. Method 17 uses an in-stack filter at duct temperature, while method 5 uses a heated (250°F) filter out of stack. Method 17 was used at the roaster and baghouse exits, and method 5 was used at the baghouse and quench tower exits.

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Condensible Material

Condensible material (sulfuric acid) at the baghouse exit was determined by combining methods 5 and 17. In addition multiple filters were used to determine the quantity of material penetrating the filter media at each sampling temperature.

Particle Sizing

Cascade impaction methods on pretreated substrate filters were used for particle sizing. Because of stream conditions, a slightly different sampling technique was used at each of the major gas stream sampling locations. At the roaster exit (Site 1) a Brinks in-stack impactor with a pre-cut cyclone was used. The Brinks impactor with precyclone was necessary because of the high grain loading. At Site 2 (baghouse exit), a standard in-stack Andersen cascade impactor was used. The quench tower exit streams (Site 3) was saturated with water. An out-of-stack Andersen sampler was used here in an oven heated to 250°F.

Integral Element Sampling

The Radian Wet Electrostatic Precipitator (WEP) and associated train (Figure 6) was used to sample gaseous and particulate material in each gas stream for quantitative analysis. A metered volume of gas was drawn isokinetically from the stream and passed through the sample collection device. The gas entering the WEP was first scrubbed and cooled in the round bottom flask. Particulates and mist not retained here were electrically charged in the glass cylinder, collected in the falling film and washed into the electrolyte reservoir. The nozzle and probe liner were glass or teflon, depending on stream temperature. Both nozzle and probe liner were washed after sampling. The washing solution was ultra pure nitric acid. This sampling device does not clog like a filter or a thimble and no analytical background corrections are necessary since no extraneous material is introduced as is the case with filters. Mercury vapors pass through this device. They were collected on gold plated glass wool as an amalgam.

Vapor Phase Constituents

Certain compounds potentially vaporize at roaster temperature and recondense as the gases cool. Elements still in the vapor phase at 250°F were determined with the vapor phase train. This was an EPA method 5 train backed up by a series of 4 impingers, the first two containing nitric acid and the last two containing sodium hydroxide solution. The gas stream was sampled isokinetically with the EPA filter removing particulate material at 250°F. Remaining gases were passed through the impinger train where the compounds present as vapors were removed.

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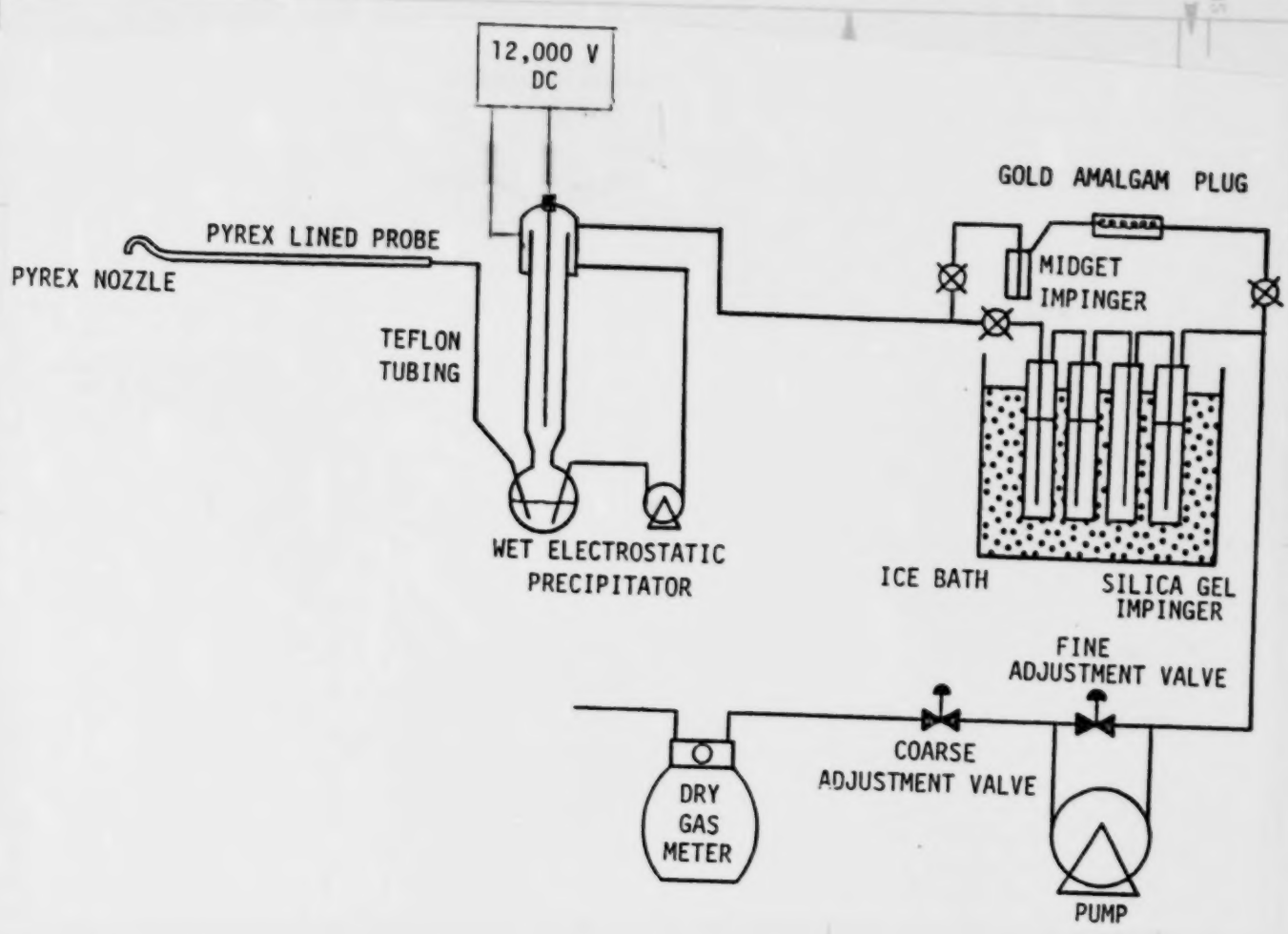


Figure 6. Wet electrostatic precipitator (WEP) impinger train used to collect gases and particulates from gas streams.

SECTION 4

FLOW RATE CALCULATIONS

Flow rates for the solid, liquid, and gaseous streams were derived, where possible, from direct measurements. This approach was not feasible for the MoO_3 production rate and the water flow rate to the quench scrubber. These two parameters were calculated by material balance calculations. The following chapters give details for the methods of calculation. The results are summarized in Table 6.

Ore Feed Rates

The ore feed was comprised of Twin Buttes concentrate, Questa concentrate, and baghouse recycle dust. The flow rates for an individual feed component were calculated from the company log. Two numbers were determined for each material, the average rate during the sampling period and the 24 hour average. The numbers are calculated by summing the pounds fed in each charge (taken directly from the company log) and dividing by the appropriate time period. The equation is:

$$F_A = \frac{1}{t} \sum_{i=1}^{i=n} (F_A)_i$$

where

F_A = average feed rate of component A over time t ((lbs/hr)

t = time period (hr)

$(F_A)_i$ = component A fed to roaster in the i th charge (lbs)

n = number of charges in the time period t

Roaster Exit Rates

Roaster exit particulate mass flow rates are calculated from grain loading, concentrations, and velocity data. The formulas are:

$R = k_1 \cdot L_R \cdot V_R$ where

$V_R = \frac{1}{4}\P \cdot d_R^2 \cdot \overline{V}_R$ (scf/min)-Volume flow rate of gases exiting roaster (scf/min).

TABLE 6. SUMMARY TABLE OF MASS AND VOLUME FLOW RATES

	1 Roaster Exit	2 Baghouse Exit	3 Quench Exit	4A Questa Ore	4B Twin Buttes Ore	5A Baghouse Dust Feed	5B Baghouse Dust Recovery	6 Quench Injection Water	7 Quench Blow Down Water	8 Product MoO_3
6/20										
Solids (lbs/hr)	-	-	30	1470	180	150	-	918	930	(1345 lb/hr)[5]
Liquids (gal/min)	-	2.0	6.7[1,3]	-	-	-	-	34.7	30.0	-
Gas (ACFM)	-	20100	15200	-	-	-	-	-	-	-
Temp (°R)	-	832	517	-	-	-	-	-	-	-
Press ("Hg)		28.49	28.81	-	-	-	-	-	-	-
6/21										
Solids (lbs/hr)	-	48	29	1317 (1368)[2]	161 (168)[2]	322 (265)[2]	328 (219)[2]	902	910	(1345 lb/hr)[5]
Liquids (gal/min)	-	2.2	7.2[1,3]	-	-	-	-	34.1	26.6	-
Gas (ACFM)	-	20500	16200	-	-	-	-	-	-	-
Temp (°R)		853	571	-	-	-	-	-	-	-
Press ("Hg)		28.38	28.80	-	-	-	-	-	-	-
6/22										
Solids (lbs/hr)	-	48	41	1470 (1420)[2]	180 (153)[2]	150 (127)[2]	303 (202)[2]	962	966	(1345 lb/hr)[5]
Liquids (gal/min)	1.8	2.1	7.3[1,3]	-	-	-	-	36.4	30.0	-
Gas (ACFM)	17700	19500	16400	-	-	-	-	-	-	-
Temp (°R)	1086	875	569	-	-	-	-	-	-	-
Press ("Hg)	28.57	28.46	28.87	-	-	-	-	-	-	-
6/23										
Solids (lbs/hr)	341	46	-	1650 (1581)[2]	-	150 (150)[2]	302 (274)[2]	(915)[4]	912	1345 lb/hr[5]
Liquids (gal/min)	1.6	2.0	(7.3)[4]	-	-	-	-	(34.6)	31.9	-
Gas (ACFM)	17700	22300	(17500)[4]	-	-	-	-	-	-	-
Temp (°R)	1050	859	569	-	-	-	-	-	-	-
Press ("Hg)	28.31	28.51	28.81	-	-	-	-	-	-	-

[1] Calculated by difference.

[2] First number is average during sampling period. Number in parenthesis is 24 hr. average.

[3] Saturated at gas temperature.

[4] Estimates from up stream flow rates.

[5] Calculated from Mo balance.

R = Mass flow out of roaster (lbs/hr)

k_1 = Units conversion constant = 8.57×10^{-3} (lb min/grain hr)

L_R = Grain loading in the stream (grains/scf).

d_R = Roaster duct diameter at sampling point (ft).

$\bar{v}_R$ = Average gas velocity at sampling point (ft/min).

Product Rate (Calculcated)

The physical layout of the product recovery system precluded obtaining a direct measure of production rates. The production rate was calculated from the Questa ore feed rate of 1650 lbs/hr, the recycle dust feed rate of 150 lbs/hr, and the roaster exit dust loading of 341 lbs/hr determined on June 23. (The dust loading was calculated from a gas flow rate of 8500 scfm and an average grain loading of 4.68 gr/scf). The molybdenum assay in the feed was 47%, translating to 78% MoS_2. The roaster dust is almost exclusively MoS_2 as determined by X-Ray diffraction. Thus, the remainder of the feed is inert material carried out in the product. The effective feed rate to the roaster is 1459 lbs/hr consisting of 321 lbs/hr inerts and 1138 lbs/hr pure MoS_2. The 1138 lbs/hr MoS_2 convert to 1024 lbs/hr MoO_3. The roaster product rate is the sum of the 1024 lbs/hr of the MoO_3 plus the 321 lbs/hr inerts or 1345 lbs/hr.

Baghouse Dust Collection Rate

Baghouse dust was collected in bins and weighed every 24 hours. The collection rate in lbs/hr is then:

$$B_D = \frac{WT}{24}$$

where WT is the weight of material collected in a 24 hour period.

Baghouse Exit

The baghouse exit flow rates are calculated in the same manner as the roaster exit streams.

Dilution Air and Volume Flow Rate Check

The dilution air rate was calculated and a heat balance carried out to verify the volume flow rate measurements. Dilution air is initially determined by subtracting the roaster exit flue gas volume of 8500 scfm from the baghouse exit gas volume of 13100 scfm giving a dilution air rate of 4600 scfm. The heat balance check is carried out by looking at the heat loss of the roaster exit gas to the ambient dilution air. The formula is:

$$M_1 \cdot C_{P_1} \quad (T_R - T_E) = M_2 \cdot C_{P_2} \quad (T_E - T_A)$$

where

M_1 = gas flow at roaster exit (scfm)

M_2 = dilution air flow (scfm)

C_{P_1} = heat capacity of roaster exit gas (cal/scf °R)

C_{P_2} = heat capacity of baghouses exit gas (cal/scf °R)

T_R = temperatures of roaster exit gases (°R)

T_E = temperatures of baghouse exit (°R)

T_A = Ambient temperature (°R)

By assuming $C_{P_1} = C_{P_2}$ and rearranging, the following expression is obtained:

$$\frac{M_1}{M_2} = \frac{T_R - T_E}{T_E - T_A} = 0.60$$

This should be equivalent to the ratio obtained by substituting previously made volume determinations.

$$\frac{13100 - 8500}{8500} = 0.54$$

Both values are in good agreement.

Quench Water Injection Rate

The quench water injection rate is calculated as the difference between the water content of the incoming gas streams (average 2 gal/min) and the sum of the water in the exiting gas and blow down stream (7.0 gal/min + 29 gal/min). This rate averages 34 gal/min.

SECTION 5

CHEMICAL ANALYSIS

The chemical characterization of the samples was based on a semiquantitative survey analysis by Spark Source Mass Spectrometry (SSMS), followed by the quantitative determination of the following fifteen elements:

Arsenic	Bismuth	Nickel
Lead	Antimony	Copper
Molybdenum	Cadmium	Manganese
Mercury	Silver	Iron
Selenium	Zinc	Rhenium

Sample preparation for analysis consisted of dissolution of the solids in Teflon® containers using HF/HNO_3 acid mixtures. Acid blanks were carried through the analysis scheme.

The SSMS analysis covers approximately 70 elements of the periodic chart. Accuracy of this technique is about one order of magnitude. Detection range is 1 ppm to 1000 ppm for solids and 0.02-10 ppm for liquid samples. Element concentrations above these limits are listed as >1000 and >10 in the results section (Section 6.0). No value at all is given for species below the detection limit.

The quantitative procedures are predominantly based on atomic absorption using flame aspiration and the graphite furnace attachment. Mercury is measured using a flameless AA technique and selenium by fluorometry. Detection limits and accuracies obtainable by these methods are listed in Table 7. The following paragraphs briefly describe the quantitative analytical methods used.

Inorganic Analyses

Copper, Iron, Manganese, Molybdenum, Lead, Zinc--

WEP solutions, liquid samples, and solid digestions were analyzed for these elements by use of flame atomic absorption (AA). The guidelines described in the operating manual were followed. Standard solutions were used to calibrate the instrument (PE-114).

TABLE 7. DETECTION LIMITS AND ACCURACIES OF THE QUANTITATIVE ANALYTICAL METHODS

Element	Detection Limit ppm Solids*	Liquids	Accuracy (%)
Arsenic	5	.05	10
Lead	2	.02	10
Molybdenum	1	.01	10
Mercury	5	.05	15
Selenium	1	.01	10
Bismuth	5	.05	10
Antimony	5	.05	10
Cadmium	1	.01	10
Silver	2	.02	10
Zinc	5	.05	10
Nickel	5	.05	10
Copper	5	.05	10
Manganese	5	.05	10
Iron	2	.02	10
Rhenium	10	.1	10

*Based on digestion of 1g solid/100 ml volume

Silver, Bismuth, Cadmium, Nickel, Rhenium, Antimony--

These elements are analyzed by direct injection into the heated graphite atomizer of the AA pectrophotometer using the standard conditions of operation described in the attachment operating manual (PE-082). A calibration curve is used for quantitation.

Arsenic--

The arsenic in WEP solutions, liquid samples, and acid digestions of solids is complexed in acidic medium as the heteropoly acid of molybdenum (RA-147). An aqueous aliquot is injected into the heated graphite atomizer. A high charring temperature of 1200°C is compatible with this method. This is desired for interference removal.

Selenium--

Selenium is determined by the use of fluorometry (LE-068, RA-082, TU-028). Aqueous selenium solutions are heated with hydrochloric acid. Following stabilization with formic acid, hydroxylamine-hydrochloride, and EDTA, the samples are complexed with 2,3-diaminonaphthalene. The selenium complex is extracted into cyclohexane and compared by fluorometry with extracted selenium standards.

Mercury--

Mercury in gaseous and solid samples is determined using a double gold amalgamation procedure (KA-086, DI-043, OG-004).

Gas samples are drawn through a plug of gold wool. Deamalgamation is accomplished by heating the gold wool with a nichrome wire heating element. The released mercury is purged with argon through the absorption cell of an atomic absorption spectrophotometer.

Solid samples are analyzed for mercury by weighing a sample into a platinum boat and heating the sample slowly in a chamber. The off-gases containing elemental mercury are purged through a gold plug, where the mercury is collected. Deamalgamation and determination by AA followed the same procedure as described above.

Liquid samples are aliquoted, acidified and the mercury oxidized with potassium permanganate. Hydroxylamine hydrochloride and stannous chloride are used to reduce the mercury to the metallic state. Air is bubbled through the solution. The mercury entrained in air is passed through the absorption cell of the AA spectrophotometer and analyzed as before.

Standards for gaseous and solid mercury determinations are derived by use of gas samples saturated with mercury vapor. The instrument is calibrated by injecting varying aliquots.

Liquid mercury standards for calibration purposes are prepared from stock AA solutions.

Gas Analyses

Carbon dioxide, carbon monoxide, nitrogen and oxygen were collected as grab samples in gas sample bags and returned to the mobile laboratory. Analysis by gas chromatography was performed with a Fisher Model 1200 gas partitioner equipped with conductivity detector.

EPA method 6 guidelines were used for collection of sulfur oxide samples. The sampling train consisted of 4 impingers. The first contained 80 percent isopropyl alcohol, the second and third, 6 percent hydrogen peroxide. The fourth was empty. The impinger solutions were analyzed for sulfate by ion chromatography (DI-170).

Organics Analyses

Solid and liquid process stream samples were analyzed for organic constituents by gas chromatography. The sample was subjected to ether extraction in a soxhlet for a period of 24 hours. The resulting extract was concentrated to one milliliter and the ether exchanged with hexane. The hexane extract was analyzed on a gas chromatograph to quantify the amount of the organic constituents present.

SECTION 6

RESULTS

This section describes the results of the chemical and physical investigations. Summaries of flows, survey analyses by SSMS, quantitative results for the fifteen elements of interest and elemental material balances are given for:

- the roaster
- the baghouse, and
- the quench scrubber.

A discussion of the impurities to be expected in lime based scrubber solids and liquids is also given. Chapters describing the baghouse performance, the organic material in roaster streams, and the contribution of sulfates to grain loadings conclude the section. The results of survey analyses by Spark Source Mass Spectrometry are given in Appendix A (Figures A-1 through A-15).

Roaster Characterization and Roaster Balance (June 23-78)

The feed to the roaster was a mixture of Questa ore, Twin Buttes ore and baghouse recycle dust. The charge rate totaled 1800 lbs/hr (Table 8). Samples to characterize the roaster were collected on June 23-78. On this day, 1650 lbs/hr Questa ore and 150 lbs/hr baghouse recycle dust were charged.

The dust flow rate at the roaster exit was determined by duct traversing. An average grain loading of 4.68 grains/scf or a mass flow of 341 lb dust/hr was found using an instack filter.

TABLE 8. FLOWS USED FOR ROASTER CHARACTERIZATION (JUNE 23-78)

Questa ore feed (MoS_2)	1650 lbs/hr
Baghouse recycle dust	150 lbs/hr
TOTAL FEED RATE	1800 lbs/hr
Baghouse catch	274 lbs/hr
Gas flow rate at roaster exit	8500 scf/min

CONTINUED

TABLE 8 CONTINUED. FLOWS USED FOR ROASTER CHARACTERIZATION (JUNE-23-78)

Grain loading measured by duct traversing average	4.68 grains/scf
Point grain loading at WEP intake	7.24 grains/scf
Dust flow rate at roaster exit	341 lbs/hr
MoO_3 production rate	1345 lbs/hr

Dust collected in the baghouse contained 49% molybdenum. The wet electrostatic precipitator catch contained .23g molybdenum per scf sampled or (assuming that the dust in the duct has the same composition as the baghouse catch) .469 solids/scf collected. This translates to a point grain loading at the WEP intake of 7.24 grains/scf.

The MoO_3 production rate of 1345 lbs/hr was calculated from the total feed rate (1800 lb/hr), the measured dust flow rate at the roaster exit (341 lb/hr) and the molybdenum concentration in the feed. The difference in molecular weight of feed and product (MoS_2: M=160, and MoO_3: M=144) was considered. The rest of the compounds in the feed, which are mainly silicates, were assumed to be inert.

Survey analyses by SSMS were performed for:

- Twin Buttes ore - Table A-1
- Questa ore - Table A-2
- Product - Table A-3, and
- WEP catch at the roaster exit - Table A-4

The heavy metal concentration was found in most cases to be in the low ppm range, with the exception of lead, zinc, copper, iron and manganese. The concentration of these species is indicated to be greater than 1000 ppm.

The quantitative analytical results in Table 9 support these findings. The Questa ore shows a higher lead content (4300 ppm) than the Twin Buttes ore (980 ppm). Whereas the Twin Buttes ore has a very high copper content relative to the Questa ore (2.4% versus 0.1%). The results for the rest of the analyses show nothing unusual, with the exception of the depletion of mercury and selenium in the product indicating volatilization in the roasting process.

TABLE 9. SUMMARY OF QUANTITATIVE ANALYTICAL RESULTS (AVERAGE OF DUPLICATE ANALYSES) (µg/g)

	Questa Ore µg/g	Twin Buttes Ore µg/g	Baghouse Dust µg/g	Product µg/g	WEP (µg/scf) (corrected for point to average grain loading.)
As	12	9.9	48	19	15
Pb	4300	980	6000	4800	1780
Mo	470000	360000	490000	540000	149000
Hg	.15	0.15	.23	.023	.22 (Au-Am)
Se	56	122	400	2.0	157
Bi	280	63	350	160	113
Sb	21	<24	27	19	7.0
Cd	18	14	22	20	7.6
Ag	38	62	52	49	14.2
Zn	1500	240	1900	1700	485
Ni	96	20	55	59	8.4
Cu	950	24000	3700	1500	401
Mn	730	840	770	890	197
Fe	11800	32500	17800	17000	3750
Re	<10	<10	<10	<10	<28

TABLE 10. ROASTER MATERIAL BALANCE (lb/hr)

Element	Ore Feed (1650 lb/hr)	Dust Feed (150 lb/hr)	Σ in 1800 lb/hr	Roaster Dust 341 lb/hr	Product 1345 lb/hr	Σ out 1686
Arsenic	0.020	.007	.027	.017	.025	.042
Lead	7.1	.90	8.0	2.00	6.44	8.44
Molybdenum	780.	74	854	168	725	893
Mercury	2×10^{-4}	$.3 \times 10^{-4}$	2.3×10^{-4}	2.5×10^{-4}	$.3 \times 10^{-4}$	2.8×10^{-4}
Selenium	.092	.060	.152	.18	.003	.183
Bismuth	.46	.05	.51	.13	.21	.34
Antimony	.035	.004	.039	.008	.025	.033
Cadmium	.030	.003	.033	.009	.027	.035
Silver	.063	.008	.071	.016	.066	.082
Zinc	2.48	.29	2.77	.55	2.28	2.83
Nickel	.16	.008	.17	.009	.079	.09
Copper	1.6	.56	2.2	.45	2.0	2.45
Manganese	1.2	.12	1.3	.22	1.19	1.4
Iron	20	2.7	22.7	4.22	22.8	27.0
Rhenium	<10	<10	<20	<10	<10	<20

The analytical results in Table 9 were combined with the flow rates (Section 4) to arrive at the element flows shown in Table 10. The balance closure is satisfactory for most elements. Exceptions are arsenic, bismuth, and nickel. Reanalysis of the samples for these two elements did not point to an analytical error.

Baghouse Balance

The roaster gases are cooled from 550°F to 450°F by mixing with ambient air before entering the baghouse. This raises the gas flow rate from 8500 scfm to 13,100 scfm. A grain loading of .41 grains/scf was determined at the baghouse outlet.

The analytical results of the following samples entered the baghouse material balance.

- WEP sample, baghouse inlet, June 23-78.
- Composite baghouse dust, June 23-78.
- WEP sample, baghouse outlet, June 23-78.

The results of the survey analysis of the baghouse dust are listed in Table A-5. These SSMS results indicate an element concentration in the dust of the same order of magnitude as in the Questa ore, the predominant feed material on June 23.

The SSMS analysis of the Wet Electrostatic Precipitator solution is shown in Table A-6. The results were converted from µg/ml WEP solution to µg/scf of flue gas. A drastic reduction in the trace element flow is indicated by comparing these values with the element flows at the inlet (Table A-4).

This is quantitatively shown in Table 11. A reduction in the element concentration at the baghouse outlet by a factor of ten is indicated if compared to the element concentration in the baghouse inlet dust.

Figure 7 shows the X-ray patterns from roaster feed and baghouse dust. The MoS_2 pattern of the concentrate reappears in the baghouse dust indicating that a major part of the baghouse dust still is MoS_2. In addition, there is a strong diffraction peak of MoO_3. CrK_α radiation was used for the identification of the crystalline phases.

The concentration data in Table 11 were multiplied with the flow rates of the corresponding streams (Section 4) to arrive at the elemental flows shown in Table 12. The balance closure is satisfactory for most elements with the exception of selenium, nickel and copper. Reanalysis of the inlet WEP solution (site 1) for selenium, nickel and copper, of the baghouse exit WEP liquor (site 2) for selenium, and of the baghouse dust for Cu and Ni verified the original results within 10%.

TABLE 14. BAGHOUSE ELEMENTAL ANALYSES (JUNE 23-78)

Element	Baghouse Inlet Dust (µg/scf[1])	Baghouse Dust (µg/g[2])	Baghouse Outlet Dust (µg/scf[3])
Arsenic	15	48	1.67
Lead	1780	6000	139
Molybdenum	149000	490000	11500
Mercury	.22	.23	.11
Selenium	157	400	89
Bismuth	113	350	4.8
Antimony	7.0	27	.59
Cadmium	7.6	22	.70
Silver	14.2	52	1.23
Zinc	485	1900	45.3
Nickel	8.4	55	.78
Copper	401	3700	19.3
Manganese	197	770	14.0
Iron	3750	17800	31.4
Rhenium	ND	ND	ND

[1]Roaster gas flow rate 8500 scfm
[2]Baghouse dust flow 271 lb/hr
[3]Baghouse outlet gas flow 13100 scfm
ND- Not detected

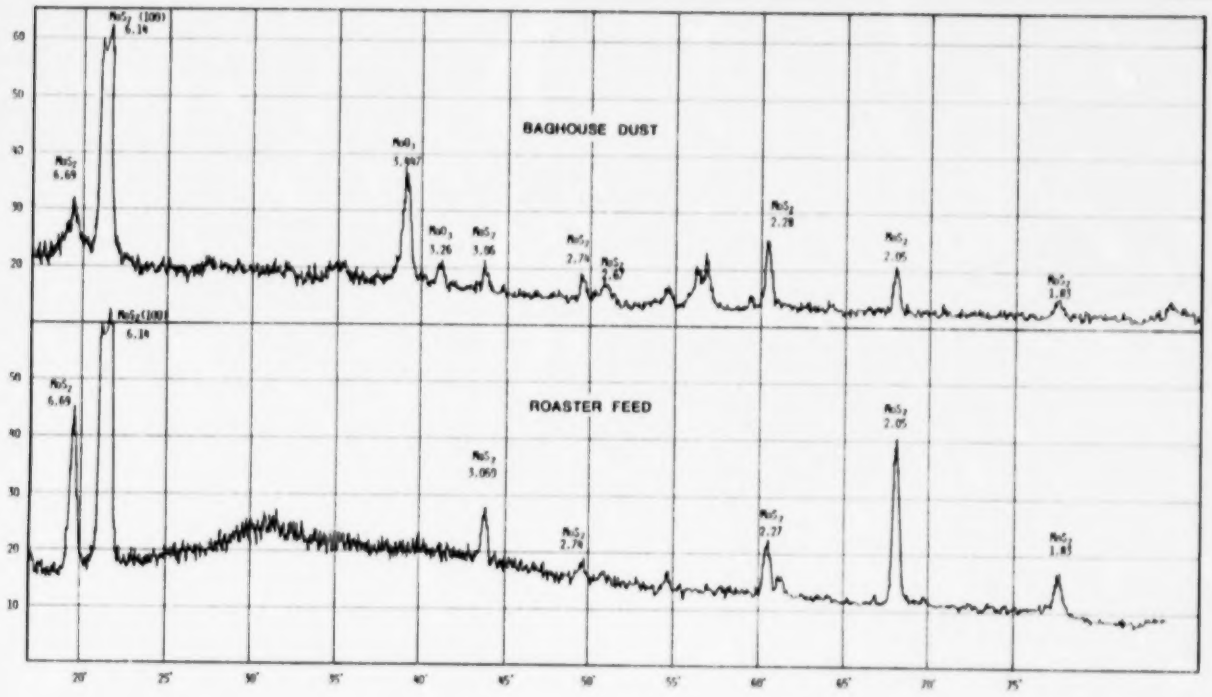


Figure 7. X-ray Diffraction Pattern Of Roaster Feed And Baghouse Dust

TABLE 12. BAGHOUSE ELEMENT BALANCES (JUNE 23-78)
ELEMENT FLOWS IN LB/HR.

Element	Roaster Gas & Dust (341 lb/hr)	Baghouse dust (272 lb/hr)	Baghouse Outlet Gas & Dust (46 lb/hr)	Σ Out (318 lb/hr)
Arsenic	.017	.013	.003	.016
Lead	2.0	1.64	.24	1.88
Molybdenum	168	134	20	154
Mercury	2.5×10^{-4}	$.6 \times 10^{-4}$	2.0×10^{-4}	2.6×10^{-4}
Selenium	.18	.11	.16	.27
Bismuth	.13	.10	.008	.11
Antimony	.008	.007	.001	.008
Cadmium	.009	.006	.001	.007
Silver	.016	.014	.002	.016
Zinc	.55	.52	.08	.60
Nickel	.009	.015	.001	.016
Copper	.45	1.0	.03	1.3
Manganese	.22	.21	.02	.23
Iron	4.22	4.88	.05	4.9
Rhenium	ND	ND	ND	

ND - Not Detected

Excellent closure is observed for arsenic, lead molybdenum, zinc, manganese, silver, mercury and antimony. From the elemental flow rate at the baghouse inlet and outlet and elemental removal efficiency of the baghouse can be derived. These efficiencies are 82% (As), 88% (Pb), 88% (Mo), 85% (Zn), 91% (Mn), 97.5% (Ag) and 87.5% (Sb), or on the average 87%.

This value is based on elemental mass balances and is, therefore, independent of factors such as sulfate contribution at the inlet and outlet and the gas dilution across the baghouse.

This removal efficiency is compared next with the removal efficiency based on grain loading measurement at the inlet (4.68 grains/scf) and the outlet (.41 grains/scf) of the baghouse. For this comparison the inlet value is adjusted for .4% sulfate contribution and the outlet adjusted for 17% sulfate contribution and dilution by a factor of 1.56. This adjustment gives a value of 4.49 grains/scf at the inlet and .53 at the outlet, indicating an elemental removal efficiency of 88%. This compares very well with the removal efficiency of 87% based on elemental mass flow rates.

The elemental flow rates for selenium and mercury in Table 14 indicate that the majority of these elements is not retained in the baghouse.

Quench - Scrubber Characterization

The exit gases from the baghouse get further cleaned in a quench scrubber. This system was characterized on June-21-78. The roaster conditions on this day are summarized in Table 13.

The following samples were analyzed using SSMS:

- WEP taken at Humidifier-Scrubber Inlet Table A-7
- WEP taken at Humidifier-Scrubber Outlet Table A-8
- WEP blank Table A-9
- Quench water inlet Table A-10
- Quench water blowdown Table A-11

A comparison of the SSMS data of the WEP taken at the Humidifier-Scrubber Outlet (µg/ml) with the WEP electrolyte blank (µg/ml) is interesting. Both solutions contain the same impurities in the same order of magnitude, with the exception of selenium and molybdenum. The concentration of these two elements is higher in the WEP solution. This is verified by the quantitative results in Table 14. Molybdenum (55 µg/scf), selenium (44 µg/scf), lead gases. These values correspond to discharge rates of 0.10 lb/hr molybdenum, 0.08 lb/hr selenium, 0.015 lb/hr lead and 0.007 lb/hr iron. About 50% of the selenium and 85% of the mercury are removed in the quench scrubber.

TABLE 13. ROASTER CONDITIONS DURING QUENCH SCRUBBER CHARACTERIZATION (JUNE-21-78)

Roaster Feed:	Questa Ore	1295 lb/hr
	Twin Buttes	159 lb/hr
	Baghouse Recycle Dust	346 lb/hr
	Total Feed Rate	1800 lb/hr
Gas Flow at Humidifier Inlet		12200 scfm
Grain Loading Inlet		.98 grains/scf*
Gas Flow at Humidifier Outlet		14400 scfm
Grain Loading Outlet		.23 grains/scf
Water Inlet Flow Rate		31.8 gal/min
Water Outlet Flow Rate		26.6 gal/min
Water Evaporation Rate		5.2 gal/min

*This value compares to 0.41 grains/scf on June-23-78.

The mass balances shown in Table 15 show good closure with the exception of Pb and Bi. Insoluble lead sulfate may be the reason for the discrepancy in the lead balance. Elemental removal efficiencies are As-77%, Pb-93%, Mo-99%, Hg-85%, Bi-95%, Sb-94%, Ag-65%, Zn-99%, Cu-95%, Mn-94%, Fe-86%. These data point to an average elemental removal efficiency of 89%.

This value is based on elemental mass balances and is, therefore, independent of factors such as sulfate contribution at the inlet and outlet and the gas dilution across the quench scrubber.

This removal efficiency is compared next with the removal efficiency based on grain loading measurement at the inlet (0.98 grains/scf) and the outlet (0.23 grains/scf) of the quench scrubber. For this comparison the inlet value is adjusted for 17% sulfate contribution and the outlet adjusted for 70% sulfate contribution and dilution by a factor of 1.2. This adjustment gives a value of 0.81 grains/scf at the inlet and 0.07 at the outlet, indicating an elemental removal efficiency of 91%. This compares very well with the removal efficiency based on elemental mass flow rates.

TABLE 14. QUANTITATIVE ANALYTICAL RESULTS FOR QUENCH SYSTEM JUNE 21-78

Element	Inlet Gas µg/scf	Inlet H_2O µg/ml	Outlet Gas µg/scf	Outlet H_2O µg/ml
Arsenic	1.60	1.3	.384	1.62
Lead	120	10.2	7.8	10.1
Molybdenum	11400	3040	55	3810
Mercury	.11	.032	.016	.061
Selenium	90	6.95	44	10.2
Bismuth	4.5	1.51	.22	3.67
Antimony	.55	.13	.03	0.39
Cadmium	.70	.55	.16	0.67
Silver	1.20	<.05	.39	0.05
Zinc	45.	43.1	.26	51.5
Nickel	.75	1.89	.078	2.22
Copper	19.	158	.78	194
Manganese	13.	39	.70	46
Iron	31	850	3.9	1000
Rhenium	<10	< 1	<10	<1

TABLE 15. MASS BALANCE QUENCH TOWER
6/21/78 (lb/hr)

Element	Baghouse Gases	Quench in H_2O	Σ in	Quench Off Gases	Quench Out H_2O	Σ out	Σ out/Σ in
As	.003	.020	.023	.0007	.022	.023	1
Pb	.21	.17	.38	.015	.134	.15	.4
Mo	19.8	48	67.8	.101	50.7	50.8	.75
Hg	.0002	.0005	.0008	3×10^{-5}	.0008	.0008	1
Se	.16	.11	.166	.08	.136	.22	1.3
Bi	.008	.02	.028	.0004	.05	.05	1.7
Sb	.001	.005	.005	6×10^{-5}	.005	.005	.83
Cd	.001	.008	.009	3×10^{-4}	.009	.009	1
Ag	.002	<.0008	.002	7×10^{-4}	<.0007	<.0014	1
Zn	.08	.68	.76	5×10^{-4}	.685	.69	.91
Ni	.001	.03	.031	$<1 \times 10^{-4}$	.030	.03	1
Cu	.033	2.5	2.5	1.5×10^{-3}	2.58	2.6	1.04
Mn	.023	.62	.64	1.3×10^{-3}	.612	.61	.95
Fe	.054	13.2	13.3	7.3×10^{-3}	13.3	13.3	1
Re	*	*		*	*		

* below detection limit

Baghouse Efficiency Study

During base line testing the baghouse was operated using three compartments on a 60 min shake cycle per compartment. These operational parameters (number of compartments and shake cycle time) were varied for the baghouse efficiency tests. Particle size distribution and grain loadings were measured simultaneously at the entrance and exit under different operational modes. The parameter matrix and primary results obtained in June are shown in Table 16. The determination of the baghouse efficiency was repeated in September. A removal efficiency of 98.2% was determined. The particle size distribution at the roaster exit is graphically shown in Figure 8.

Organics

Large quantities of organic material are introduced into the process with the ore concentrates. Flotation oils of various composition are used in the concentrating process and adhere to the ore. It was suggested by some investigators that much of the plume problem seen at this facility was due to carry over of these oils. Tests were conducted to quantitate this problem and the results are given in Table 17.

Feed and product samples, quench scrubber water samples, and filters from the quench exit sampling tests were extracted and analyzed for organics using the EPA criteria Organic Pollutant analysis protocol. Organics in the non-aqueous samples were expected to be non-acidic. Therefore, the protocol extraction scheme for basic and neutral organic materials was used. Filters were quartered, and one half (diagonal quarters) extracted with ethyl ether in a soxhlet extractor. The ether solution was concentrated, and the residue taken up in 1 ml hexane. For solid samples 3.0 grams were treated in the same manner. Because of the high acidity of the liquid samples, the acid extraction scheme was used. Liquid samples (100 ml) were extracted with chloroform, the chloroform solution concentrated, and the residue taken up in 1 ml hexane.

Quantitation was carried out by running a standard sample containing 19 EPA criteria compounds on the FID gas chromatograph and determining the average area response per nanogram. The FID (flame ionization detector) is specific for carbon compounds and its response is almost linear with the amount of carbon present. The response will vary somewhat from compound to compound, but the variation cannot be determined without specific compound identification. For semiquantitation (± 25%) an average response is used. In this analysis the total area response for the major peaks in an individual sample was divided by the response per nanogram of the standard. This number was then translated into the appropriate concentration number. For example, a 10 µl injection of quench water outlet extract gave a total area count of 14.3×10^5 units for 10 major peaks. The average area response on a standard for the day the sample was analyzed was 3.5×10^3 counts/nanogram. There were approximately 4.1×10^3 nanograms (or 4.1 micrograms) of organic material in the 10 µl injection sample. The 10 µl was taken from a total of 1 ml. Thus, 410 micrograms of organic material was

TABLE 16. RESULTS OF BAGHOUSE PERFORMANCE TESTS[5]

	Test #	1	2	3[4]	4
1	Date	6/26	6/26	6/23	6/27
2	Number of compartments	2	2	3[3]	3
3	Cycle time (min)/compartment	20	40	60	90
4	Volume Flow rate (exit) (x 10^{-4} ACFM)	2.19	2.30	2.23	2.18
5	Air to cloth ratio (ACFM/Ft^2)	1.00	1.05	0.68	0.66
6	Total gas/ft^2 cloth/cycle	20	42	41	60
7	Entrance mass flow lbs/hr	375	392	397	575
8	Exit mass flow lbs/hr*				
9	Removal efficiency (Total)*				
10	Entrance fraction >1μ	0.88	0.88	0.88	0.85
11	Quantity lbs/hr >1μ	330	306	349	489
12	Exit fraction*				
13	Quantity lbs/hr*				
14	Efficiency on*				

[1]Includes H_2SO_4 condensation
[2]Just after compartment cleaning
[3]Just prior to compartment cleaning
[4]Normal operating conditions
[5]No effort has been made to remove the effects of sulfuric acid mist from these numbers.

*Exit measurements during June were discarded due to broken bags. Removal efficiency was redetermined in September. A value of 98.2% was found (see Appendix Z).

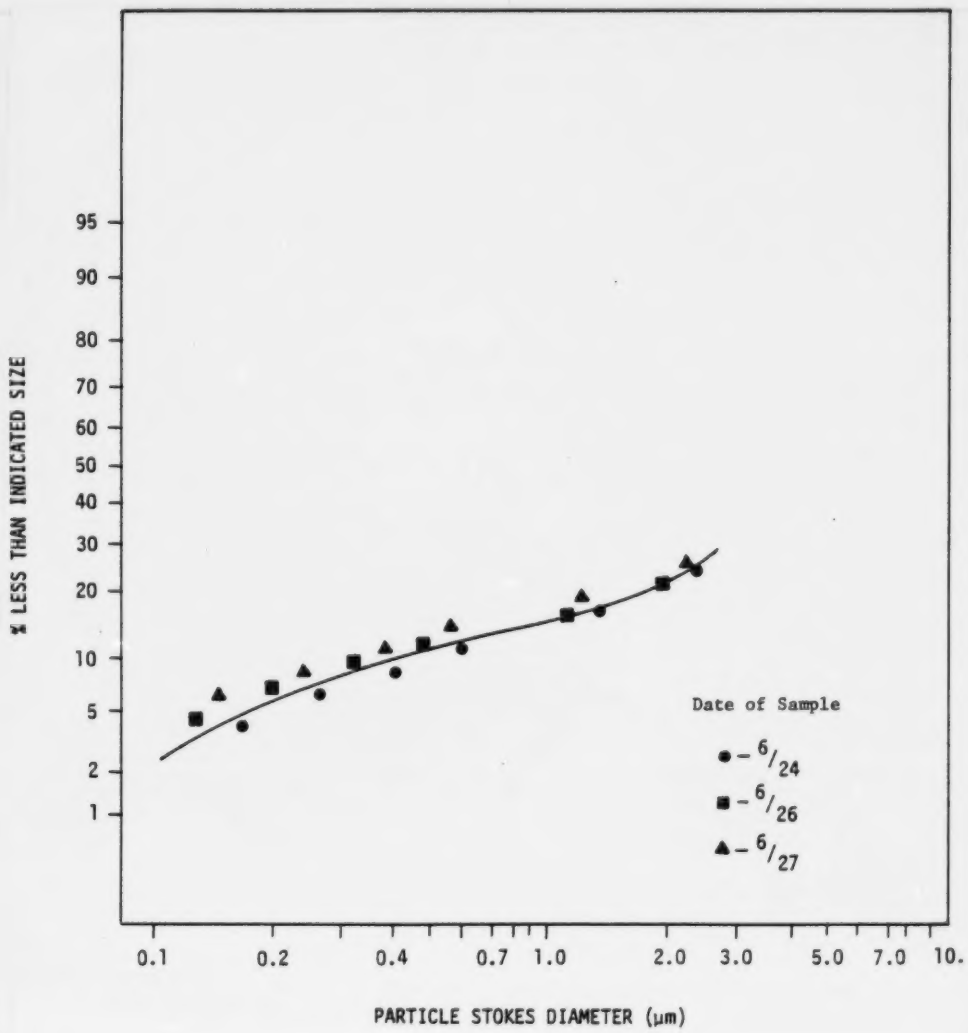


Figure 8. Roaster Exit Particle Size Distribution, (Site 1).

TABLE 17. CONCENTRATION OF ORGANIC COMPOUNDS IN PROCESS STREAMS

1.	Quench exit			
	Run 1	First filter	1.04 µg/scf	
		Second filter	6.64 µg/scf	
		Total		7.7 µg/scf
	Run 2	First filter	1.88 µg/scf	
		Second filter	5.55 µg/scf	
		Total		7.4 µg/scf
2.	Quench injection water			11 mg/gal
3.	Quench blowdown water			15 mg/gal
4.	Baghouse dust			0.4 mg/lb
5.	Questa Ore Bin 6			144 mg/lb
6.	Questa Ore Bin 8			145 mg/lb
7.	Twin Buttes Ore			40 mg/lb
8.	Product Molybdenum Oxide			39 mg/lb

extracted from 100 ml of original sample. This translates to 4.1 milligrams/l or about 15.5 milligrams/gallon.

A visual inspection of the chromatograms obtained showed differences in the amount of organic material present in the various samples. The results of these tests for the scrubber exit (∿8 µg/scf) show that organics were not a problem.

Sulfate Contributions to Grain Loading

Sulfates arise in the system from the oxidation of sulfur dioxide to sulfur trioxide. There are two potential fates of the SO_3. It may react directly with metal oxides in the gas phase to form particulate sulfates, or it may react with the water vapor present to form sulfuric acid. At the roaster exit the dew point for sulfuric acid is 309°F (calculated from 97 ppm average SO_3 content and 4.2% water. This is well below the 600°F temperature of the flue gas at this point. At the baghouse exit (containing ∿ 16 ppm SO_3 and 3.4% water) the dew point is 269°F. This is again well below the 450°F temperature of the exit gases. The scrubber exit temperature is below the acid dew point.

Sampling procedures were designed to determine the amount of SO_3 in the stream, not the amount of H_2SO_4. Thus, in-stack filters were used at the roaster exit and baghouse exit. The SO_3 passing through the filter is trapped in an isopropanol-water mixture. This solution decreases the solubility of SO_2 and prevents the oxidation of SO_2 to SO_3. The saturated condition at the scrubber exit requires heating the gas stream and an out of stack filter. By varying the filter temperature an indication of the amount of particulate sulfate versus sulfuric acid can be determined.

Sulfate contribution to grain loadings (i.e., sulfate found on the filter) was 0.4%, 17%, and 50-90% for the roaster exit, baghouse exit, and quench scrubber, respectively (Table 6-11). Conversely, the SO_3 levels (SO_3 penetrating the filter) decrease on the order of 59 ppm (corrected for dilution) and 15 ppm. The quench scrubber exit values of 55, 37, and 18 ppm SO_3 are out of the pattern because of the heated filter effects and sulfate introduced by the scrubber (discussed below).

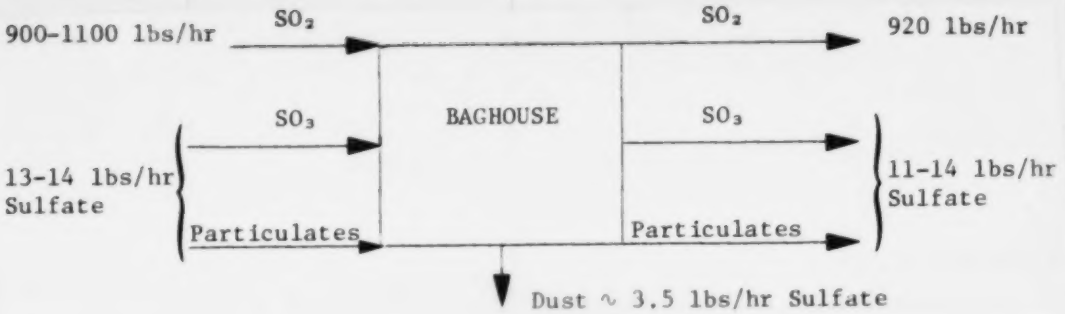
A sulfate balance around the baghouse is of interest. A calculated rate of about 13-14 lbs/hr in (particulate sulfate plus SO_3) vs. 15-17 lbs/hr out (11-14 lbs/hr in the gas stream and ∿ 3.5 lbs/hr with the recovered dust) indicates both sorption of sulfate and oxidation of SO_2. The amount of oxidation necessary to account for the increase in sulfate is negligible (about 20 ppm at 14,000 SCFM gas flow rate). The decrease in SO_2 would not be detected in the 8,000 to 10,000 ppm SO_2 concentration seen in this gas stream. The experimental error associated with the SO_2 measurements would be sufficient to swamp the small change expected.

TABLE 18. CONTRIBUTION OF SULFATES TO MEASURED GRAIN LOADINGS

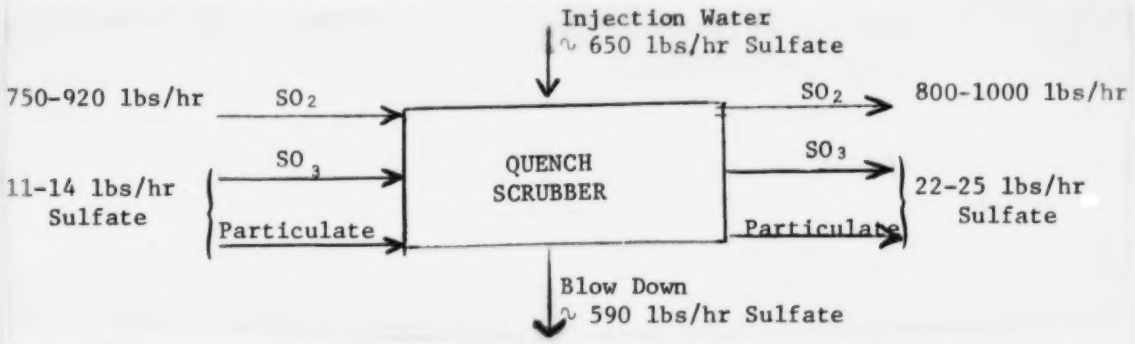
Site	Roaster Exit	Baghouse Exit			Quench Scrubber Exit			
Date	6/23	6/21	6/21	6/23	6/20	6/20	6/21	6/22
Particulate Collection Temperature °F	600	450	450	450	380	365	300	250
Total grains/scf	5.67, 3.69	-*	.84	.44	.22	.31	.23	.43
Sulfate Contribution 1. Filter grains/scf	.02	-*	.09	.10	.05	.06	.13	.33
Sulfate Contribution 2. Filter grains/scf	-	.08	-	-	.06	.05	.04	.06
% Sulfate Contribution to total grain loading	0.4%	-	11%	23%	50%	35%	74%	91%
Total SO_3 in gas ppm (collected on impinger after filters)	90	14	20	7	55	37	18	-
Potential additional sulfate contributes to grain loading	.17	.03	.04	.01	.10	.07	.03	-
Total Sulfate in stream (g/scf) as H_2SO_4	.19	.11	.13	.11	.21	.18	.20	-
Sulfate rate as H_2SO_4 lbs/hr	13.5	11.2	13.8	12.5	25	22	25	-

*Filter lost.

Note: Sulfate in Quench Water blowdown 436 mmoles/1
Sulfate in Quench water injection 372 mmoles/1



By calculating the sulfate rate through the scrubber, a major source of sulfate in the exit gases is made apparent. Going into the quench scrubber, the sulfate loading ranges from 11-14 lbs/hr (as sulfuric acid) in the flue gas. Leaving the scrubber, in the flue gas loading is 22-25 lbs/hr, or approximately double the incoming sulfate loading. The quench scrubber is adding sulfate to the gas stream either by SO_2 oxidation, evaporation, or mist entrainment. This is not unreasonable. The injection water is ∿0.4 molar sulfate with a pH of <0.5 (i.e., almost 1 normal sulfuric acid). An evaporation or reentrainment rate of less than 1 gal/min would be sufficient to add the extra sulfate to the gas stream.



Sulfate as sulfuric acid mist contributes from 50 to 90% to the final grain loading leaving the quench scrubber. Of this, at least half is directly attributable to the quench injection water. Table 18 shows the distribution of sulfate in the various tests as a function of collection temperature.

As is expected, with lower collection temperature more sulfate is collected as particulate and less SO_3 passes through the filters of the sampling train. At normal collection temperature (∿ 250°F) as much as 90% of the particulate material is sulfate as sulfuric acid. The proof that the material is sulfuric acid mist (as opposed to particulate sulfate) is in the decreasing amount of sulfate on the filters with increasing temperature with no change in the total sulfate. As the temperature is increased, the rising partial pressure of sulfuric acid allows more SO_3 to pass the filter. Particulate sulfate would not be affected in the same magnitude at the temperatures under study.

Vapor Phase Elements

Several elements associated with the ore potentially form compounds that volatilize at roaster temperature. Among these elements are lead, cadmium, arsenic, antimony, selenium and mercury. Volatilized compounds condense as the roaster off-gases cool. An EPA Method 5 train (held at 250°F) followed by impingers was used to determine elements in the vapor phase at 250°F at the roaster exit, baghouse exit and quench scrubber exit.

The results are shown in Table 19. The amounts determined were either very low or below the detection limits of the analytical methods used. This confirms earlier presented results, that the species volatilized in the roaster-like selenium and mercury - are recondensed at the flue gas discharge temperature of 120°F.

TABLE 19. VAPOR PHASE ELEMENTS

Site	Roaster Exit	Baghouse Exit	Quench Exit
Date	6/23	6/22	6/22
Gas Flow Rate (SCFM)*	8970	11710	14990
Element/Units	lbs/hr	lbs/hr	lbs/hr
Molybdenum	<.06	<.08	<.05
Lead	<.06	<.08	<.05
Arsenic	.02	.04	.05
Antimony	.15	.19	<.09
Selenium	<.14	<.16	<.10
Nickel	.007	.004	.006
Mercury	<.06	<.05	<.08
	3×10^{-5}	4×10^{-5}	7×10^{-6}

* 70°F and 1 atm. pressure

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APPENDIX A

RESULTS OF SURVEY ANALYSES BY SPARK SOURCE MASS SPECTROMETRY

TABLE A-1. SSMS ANALYSES OF TWIN BUTTES ORE
(SAMPLE NO. 1446)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	8	Terbium	0.2	Ruthenium		Vanadium	22
Thorium	3	Gadolinium	0.9	Molybdenum	>1000	Titanium	INT
Bismuth	90	Europium	0.5	Niobium	3	Scandium	5
Lead	430	Samarium	2	Zirconium	19	Calcium	>1000
Thallium	1	Neodymium	6	Yttrium	17	Potassium	480
Mercury	NR	Praseodymium	*2	Strontium	47	Chlorine	13
Gold	0.2	Cerium	*14	Rubidium	25	Sulfur	>1000
Platinum		Lanthanum	*12	Bromine	10	Phosphorus	50
Iridium		Barium	31	Selenium	290	Silicon	>1000
Osmium		Cesium	3	Arsenic	49	Aluminum	120
Rhenium	140	Iodine	14	Germanium	7	Magnesium	MC
Tungsten	26	Tellurium	22	Gallium	10	Sodium	300
Tantalum	$\leq$4	Antimony	41	Zinc	>1000	Fluorine	>1000
Hafnium		Tin	26	Copper	>1000	Oxygen	NR
Lutetium		Indium	STD	Nickel	210	Nitrogen	NR
Ytterbium		Cadmium	170	Cobalt	22	Carbon	NR
Thulium		Silver	120	Iron	>1000	Boron	0.2
Erbium	0.5	Palladium		Manganese	>1000	Beryllium	
Holmium	0.6	Rhodium		Chromium	6	Lithium	4
Dysprosium	*1					Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-2. SSMS ANALYSIS OF QUESTA ORE
(SAMPLE NO. 1412)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	15	Terbium	0.4	Ruthenium		Vanadium	39
Thorium	22	Gadolinium	1	Molybdenum	> 1000	Titanium	INT
Bismuth	40	Europium	0.5	Niobium	11	Scandium	12
Lead	>1000	Samarium	2	Zirconium	27	Calcium	>1000
Thallium	0.7	Neodymium	6	Yttrium	14	Potassium	>1000
Mercury	NR	Praseodymium	3	Strontium	33	Chlorine	8
Gold		Cerium	12	Rubidium	8	Sulfur	>1000
Platinum		Lanthanum	43	Bromine	0.8	Phosphorus	>1000
Iridium		Barium	44	Selenium	110	Silicon	>1000
Osmium		Cesium	1	Arsenic	43	Aluminum	>200
Rhenium	11	Iodine		Germanium	1	Magnesium	>1000
Tungsten	5	Tellurium	38	Gallium	5	Sodium	20
Tantalum	≤2	Antimony	72	Zinc	>1000	Fluorine	≈320
Hafnium		Tin	19	Copper	930	Oxygen	NR
Lutetium		Indium	STD	Nickel	210	Nitrogen	NR
Ytterbium		Cadmium	67	Cobalt	40	Carbon	NR
Thulium		Silver	220	Iron	> 1000	Boron	0.3
Erbium	0.9	Palladium		Manganese	> 1000	Beryllium	
Holmium	1	Rhodium		Chromium	24	Lithium	7
Dysprosium	2					Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-3. SSMS ANALYSIS OF MoO_3 PRODUCT
(SAMPLE NO. 1443)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	20	Terbium	0.7	Ruthenium		Vanadium	42
Thorium	32	Gadolinium	3	Molybdenum	>1000	Titanium	INT
Bismuth	77	Europium	0.9	Niobium	23	Scandium	3
Lead	> 1000	Samarium	9	Zirconium	29	Calcium	> 1000
Thallium	11	Neodymium	9	Yttrium	16	Potassium	> 1000
Mercury		Praseodymium	5	Strontium	24	Chlorine	42
Gold	≤ 0.2	Cerium	32	Rubidium	13	Sulfur	> 1000
Platinum	≤ 2	Lanthanum	58	Bromine	4	Phosphorus	> 1000
Iridium		Barium	60	Selenium	7	Silicon	> 1000
Osmium		Cesium	1	Arsenic	47	Aluminum	> 1000
Rhenium	2	Iodine	10	Germanium	1	Magnesium	> 1000
Tungsten	10	Tellurium	42	Gallium	15	Sodium	> 1000
Tantalum		Antimony	78	Zinc	>1000	Fluorine	= 160
Hafnium		Tin	51	Copper	>1000	Oxygen	NR
Lutetium		Indium	STD	Nickel	75	Nitrogen	NR
Ytterbium	1	Cadmium	330	Cobalt	34	Carbon	NR
Thulium	0.2	Silver	75	Iron	>1000	Boron	5
Erbium	0.7	Palladium		Manganese	>1000	Beryllium	
Holmium	1	Rhodium		Chromium	52	Lithium	11
Dysprosium	2					Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-4. SSMA ANALYSIS OF WEP SOLUTION COLLECTED AT SITE 1 (JUNE 23-79) SAMPLE NO. 1418

CONCENTRATION IN µg/sct

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	7	Terbium		Ruthenium		Vanadium	3.5
Thorium	7	Gadolinium		Molybdenum	>360	Titanium	INT
Bismuth	29	Europium	.1	Niobium	3.5	Scandium	< .1
Lead	>360	Samarium	.7	Zirconium	1.4	Calcium	> 360
Thallium	3.5	Neodymium	3.7	Yttrium	2.5	Potassium	> 360
Mercury	-	Praseodymium	1.8	Strontium	7.1	Chlorine	11
Gold		Cerium	21	Rubidium	3.2	Sulfur	> 360
Platinum		Lanthanum	21	Bromine	.7	Phosphorus	> 360
Iridium		Barium	18	Selenium	2.1	Silicon	290
Osmium		Cesium	.3	Arsenic	7	Aluminum	>70
Rhenium	<.2	Iodine	3.5	Germanium	.1	Magnesium	> 360
Tungsten	3.5	Tellurium	25	Gallium	2.5	Sodium	>210
Tantalum		Antimony	14	Zinc	> 360	Fluorine	~140
Hafnium		Tin	1.8	Copper	> 360	Oxygen	NR
Lutetium		Indium	STD	Nickel	14	Nitrogen	NR
Ytterbium		Cadmium	25	Cobalt	7	Carbon	NR
Thulium		Silver	32	Iron	> 360	Boron	.7
Erbium		Palladium		Manganese	290	Beryllium	1.4
Holmium		Rhodium		Chromium	3.5	Lithium	3.5
Dysprosium						Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-5. SSMS ANALYSIS OF BAGHOUSE DUST
(SAMPLE NO. 1445)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	10	Terbium	≤0.2	Ruthenium		Vanadium	22
Thorium	*17	Gadolinium	1	Molybdenum	>1000	Titanium	INT
Bismuth	300	Europium	0.5	Niobium	15	Scandium	2
Lead	>1000	Samarium	2	Zirconium	19	Calcium	>1000
Thallium	0.7	Neodymium	13	Yttrium	17	Potassium	>1000
Mercury	NR	Praseodymium	6	Strontium	83	Chlorine	13
Gold	≤0.1	Cerium	30	Rubidium	10	Sulfur	>1000
Platinum		Lanthanum	30	Bromine	3	Phosphorus	670
Iridium		Barium	56	Selenium	480	Silicon	>1000
Osmium		Cesium	2	Arsenic	81	Aluminum	>120
Rhenium	13	Iodine	≤5	Germanium	7	Magnesium	>1000
Tungsten	9	Tellurium	220	Gallium	4	Sodium	50
Tantalum	≤4	Antimony	91	Zinc	>1000	Fluorine	≈140
Hafnium		Tin	47	Copper	>1000	Oxygen	NR
Lutetium		Indium	STD	Nickel	48	Nitrogen	NR
Ytterbium		Cadmium	85	Cobalt	22	Carbon	NR
Thulium		Silver	160	Iron	>1000	Boron	0.7
Erbium	0.5	Palladium		Manganese	>1000	Beryllium	
Holmium	0.6	Rhodium		Chromium	6	Lithium	4
Dysprosium	1					Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-6. SSMS ANALYSIS OF THE WEP-SAMPLED AT SITE 2 (SAMPLE NO. 1416)

CONCENTRATION IN µg/scf

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	2
Thorium		Gadolinium		Molybdenum	>35	Titanium	
Bismuth	3	Europium		Niobium	.04	Scandium	<.02
Lead	3	Samarium		Zirconium	.6	Calcium	>95
Thallium		Neodymium		Yttrium	.07	Potassium	10
Mercury	NR	Praseodymium		Strontium	.2	Chlorine	.03
Gold		Cerium	.1	Rubidium	<.01	Sulfur	>95
Platinum		Lanthanum	.06	Bromine		Phosphorus	7
Iridium		Barium	1	Selenium	5	Silicon	30
Osmium		Cesium		Arsenic	1	Aluminum	>20
Rhenium	5	Iodine		Germanium	.05	Magnesium	40
Tungsten		Tellurium	.7	Gallium	.02	Sodium	>50
Tantalum	<.4	Antimony	.4	Zinc	3	Fluorine	∿3
Hafnium		Tin	.6	Copper	6	Oxygen	NR
Lutetium		Indium	STD	Nickel	>95	Nitrogen	NR
Ytterbium		Cadmium	.04	Cobalt	.7	Carbon	NR
Thulium		Silver	<.2	Iron	50	Boron	4
Erbium		Palladium		Manganese	2	Beryllium	
Holmium		Rhodium		Chromium	1	Lithium	07
Dysprosium						Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-7. SURVEY ANALYSIS BY SSMS OF THE WEP COLLECTED AT THE HUMIDIFIER SCRUBBER INLET (JUNE 21-78) (SAMPLE NO. 1417)

CONCENTRATION IN µg/ml

ELEMENT	µg/ml	µg/scf	ELEMENT	µg/ml	µg/scf	ELEMENT	µg/ml	µg/scf	ELEMENT	µg/ml	µg/scf
Uranium	0.03	.3	Terbium	-	-	Ruthenium	-	-	Vanadium	0.06	.5
Thorium	0.03	.3	Gadolinium	-	-	Molybdenum	>10	>90	Titanium	INT	INT
Bismuth	0.3	3	Europium	-	-	Niobium	0.06	.5	Scandium	0.01	.1
Lead	3	2.6	Samarium	0.008	.07	Zirconium	0.02	.2	Calcium	>10	>90
Thallium	0.002	.02	Neodymium	0.02	.2	Yttrium	0.02	.2	Potassium	7	162
Mercury	NR	NR	Praseodymium	0.01	.09	Strontium	0.07	.6	Chlorine	0.06	.5
Gold	-	-	Cerium	0.05	.4	Rubidium	0.02	.2	Sulfur	>10	>90
Platinum	-	-	Lanthanum	0.05	.4	Bromine	0.004	.04	Phosphorus	3	27
Iridium	-	-	Barium	0.05	.4	Selenium	1	9	Silicon	1	9
Osmium	-	-	Cesium	0.003	.03	Arsenic	0.2	1.8	Aluminum	>2	>18
Rhenium	0.4	4	Iodine	0.02	.2	Germanium	0.2	.2	Magnesium	>10	>90
Tungsten	0.04	.4	Tellurium	0.6	5	Gallium	0.01	.1	Sodium	>5	>44
Tantalum	≤0.007	≤.06	Antimony	0.1	.9	Zinc	3	27	Fluorine	≈0.3	2.7
Hafnium	-	-	Tin	0.07	.6	Copper	>10	>90	Oxygen	NR	NR
Lutetium	-	-	Indium	STD	STD	Nickel	0.3	2.7	Nitrogen	NR	NR
Ytterbium	-	-	Cadmium	0.1	.9	Cobalt	0.1	.9	Carbon	NR	NR
Thulium	-	-	Silver	0.3	3	Iron	>10	>90	Boron	0.01	.1
Erbium	-	-	Palladium	-	-	Manganese	0.9	8	Beryllium	-	-
Holmium	-	-	Rhodium	-		Chromium	0.09	.8	Lithium	0.005	.04
Dysprosium	-	-							Hydrogen	NR	MR

TABLE A-8. SURVEY ANALYSIS BY SSMS OF THE WEP COLLECTED AT THE HUMIDIFIER SCRUBBER OUTLET (JUNE 21-78) (SAMPLE NO. 1419)

CONCENTRATION IN µg/ml

ELEMENT	µg/ml	µg/scf	ELEMENT	µg/ml	µg/scf	ELEMENT	µg/ml	µg/scf	ELEMENT	µg/ml	µg/scf
Uranium	-	-	Terbium	-	-	Ruthenium	-	-	Vanadium	0.004	.04
Thorium	-	-	Gadolinium	-	-	Molybdenum	>10	>90	Titanium	INT	INT
Bismuth	0.005	.04	Europium	-	-	Niobium	-	-	Scandium	≤0.003	<.03
Lead	0.02	.2	Samarium	-	-	Zirconium	0.007	.06	Calcium	>10	>90
Thallium	-	-	Neodymium	-	-	Yttrium	-	-	Potassium	3	27
Mercury	NR	-	Praseodymium	-	-	Strontium	0.009	.08	Chlorine	0.01	.1
Gold	-	-	Cerium	0.006	.05	Rubidium	<0.001	<.01	Sulfur	>10	>90
Platinum	-	-	Lanthanum	0.008	.07	Bromine	0.005	.04	Phosphorus	4	36
Iridium	-	-	Barium	0.02	.2	Selenium	1	.9	Silicon	2	18
Osmium	-	-	Cesium	-	-	Arsenic	0.1	.9	Aluminum	0.4	4
Rhenium	*0.3	3	Iodine	-	-	Germanium	0.004	.04	Magnesium	1	9
Tungsten	-	-	Tellurium	≤0.01	<.1	Gallium	0.003	.03	Sodium	2	18
Tantalum	≤0.09	<.8	Antimony	0.005	.04	Zinc	*0.2	*2	Fluorine	≈0.02	≈.2
Hafnium	-	-	Tin	0.01	.1	Copper	0.8	.7	Oxygen	NR	NR
Lutetium	-	-	Indium	STD	-	Nickel	0.1	1	Nitrogen	NR	NR
Ytterbium	-	-	Cadmium	-	-	Cobalt	≤0.004	<.04	Carbon	NR	NR
Thulium	-	-	Silver	≤0.02	<.2	Iron	3	27	Boron	≤0.001	<.01
Erbium	-	-	Palladium	-	-	Manganese	0.03	.3	Beryllium	-	-
Holmium	-	-	Rhodium	-	-	Chromium	0.03	.3	Lithium	<0.001	<.01
Dysprosium	-	-							Hydrogen	NR	NR

TABLE A-9. SURVEY ANALYSIS BY SSMS OF THE WEP ELECTROLYTE (BLANK) (SAMPLE NO. WEP-BLK)

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.04
Thorium		Gadolinium		Molybdenum	0.3	Titanium	0.3
Bismuth		Europium		Niobium	0.01	Scandium	≤0.007
Lead	0.05	Samarium		Zirconium	0.02	Calcium	8
Thallium		Neodymium		Yttrium		Potassium	0.3
Mercury	NR	Praseodymium		Strontium	0.09	Chlorine	0.1
Gold		Cerium	0.01	Rubidium		Sulfur	>10
Platinum		Lanthanum	0.03	Bromine	0.01	Phosphorus	1
Iridium		Barium	0.06	Selenium	≤0.02	Silicon	2
Osmium		Cesium		Arsenic	0.01	Aluminum	0.2
Rhenium		Iodine		Germanium	≤0.003	Magnesium	1
Tungsten		Tellurium		Gallium	0.02	Sodium	0.3
Tantalum	≤0.1	Antimony	0.02	Zinc	0.04	Fluorine	≈0.4
Hafnium		Tin	0.02	Copper	0.08	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.2	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	0.004	Carbon	NR
Thulium		Silver		Iron	1	Boron	0.03
Erbium		Palladium		Manganese	0.03	Beryllium	
Holmium		Rhodium		Chromium	0.6	Lithium	0.004
Dysprosium						Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-10. SURVEY ANALYSIS BY SSMS OF THE QUENCH WATER INLET (SAMPLE NO. 1441)

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	0.1	Terbium	0.004	Ruthenium		Vanadium	0.5
Thorium	0.2	Gadolinium	0.02	Molybdenum	>10	Titanium	INT
Bismuth	0.4	Europium	0.008	Niobium	0.3	Scandium	0.08
Lead	4	Samarium	0.1	Zirconium	0.1	Calcium	> 10
Thallium	0.01	Neodymium	2	Yttrium	0.2	Potassium	> 10
Mercury	NR	Praseodymium	1	Strontium	3	Chlorine	0.3
Gold		Cerium	3	Rubidium	0.2	Sulfur	> 10
Platinum		Lanthanum	8	Bromine	0.02	Phosphorus	> 10
Iridium		Barium	0.02	Selenium	2	Silicon	> 10
Osmium		Cesium	< 0.001	Arsenic	1	Aluminum	> 2
Rhenium	0.2	Iodine	0.01	Germanium	0.02	Magnesium	> 10
Tungsten	0.6	Tellurium	≤ 1	Gallium	0.1	Sodium	> 5
Tantalum		Antimony	0.2	Zinc	>10	Fluorine	≈ 2
Hafnium		Tin	0.1	Copper	>10	Oxygen	NR
Lutetium		Indium	STD	Nickel	2	Nitrogen	NR
Ytterbium		Cadmium	0.7	Cobalt	2	Carbon	NR
Thulium		Silver	0.08	Iron	>10	Boron	2
Erbium	0.005	Palladium		Manganese	>10	Beryllium	
Holmium	0.008	Rhodium		Chromium	1	Lithium	0.7
Dysprosium	0.02					Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-11. SURVEY ANALYSIS BY SSMS OF THE QUENCH WATER BLOWDOWN (SAMPLE NO. 1442)

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	1	Terbium	0.05	Ruthenium		Vanadium	1
Thorium	3	Gadolinium	0.1	Molybdenum	>10	Titanium	INT
Bismuth	0.1	Europium	0.1	Niobium	1	Scandium	> 0.7
Lead	0.3	Samarium	0.9	Zirconium	1	Calcium	> 10
Thallium	0.02	Neodymium	5	Yttrium	1	Potassium	> 10
Mercury	NR	Praseodymium	2	Strontium	7	Chlorine	> 10
Gold	< 0.04	Cerium	> 10	Rubidium	0.3	Sulfur	> 10
Platinum		Lanthanum	> 10	Bromine	0.1	Phosphorus	> 10
Iridium		Barium	0.2	Selenium	>10	Silicon	> 10
Osmium		Cesium	0.02	Arsenic	0.9	Aluminum	≥ 5
Rhenium	2	Iodine	0.05	Germanium	0.1	Magnesium	> 10
Tungsten	3	Tellurium	1	Gallium	0.4	Sodium	> 10
Tantalum	< 0.08	Antimony	0.2	Zinc	>10	Fluorine	≈ 3
Hafnium		Tin	0.2	Copper	>10	Oxygen	NR
Lutetium	0.02	Indium	STD	Nickel	7	Nitrogen	NR
Ytterbium	0.1	Cadmium	0.8	Cobalt	8	Carbon	NR
Thulium	0.01	Silver	0.5	Iron	>10	Boron	6
Erbium	0.1	Palladium		Manganese	>10	Beryllium	
Holmium	0.1	Rhodium		Chromium	>10	Lithium	0.8
Dysprosium	0.2					Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-12. SSMS ANALYSIS OF LIME USED IN SO_2 SCRUBBING TESTS (SAMPLE NO. M-095)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	7	Terbium		Ruthenium		Vanadium	12
Thorium		Gadolinium		Molybdenum	10	Titanium	5
Bismuth		Europium		Niobium	0.8	Scandium	1
Lead	1	Samarium		Zirconium	4	Calcium	>1000
Thallium		Neodymium	1	Yttrium	2	Potassium	120
Mercury	NR	Praseodymium	0.3	Strontium	430	Chlorine	28
Gold		Cerium	3	Rubidium	0.4	Sulfur	62
Platinum		Lanthanum	2	Bromine	1	Phosphorus	86
Iridium		Barium	10	Selenium	1	Silicon	>1000
Osmium		Cesium		Arsenic	3	Aluminum	>200
Rhenium		Iodine		Germanium		Magnesium	>1000
Tungsten		Tellurium		Gallium	1	Sodium	26
Tantalum		Antimony	0.7	Zinc	9	Fluorine	≈560
Hafnium		Tin		Copper	3	Oxygen	NR
Lutetium		Indium		Nickel	8	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	0.4	Carbon	NR
Thulium		Silver	0.7	Iron	>1000	Boron	0.8
Erbium		Palladium		Manganese	100	Beryllium	
Holmium		Rhodium		Chromium	9	Lithium	1
Dysprosium						Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-13. SSMS ANALYSIS OF LIME SCRUBBING END PRODUCT
NO PRESCRUBBER USED
(SAMPLE NO. M-017)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	≤2	Terbium		Ruthenium		Vanadium	5
Thorium		Gadolinium		Molybdenum	5	Titanium	62
Bismuth		Europium		Niobium	0.5	Scandium	0.2
Lead	1	Samarium		Zirconium	3	Calcium	>1000
Thallium		Neodymium		Yttrium	2	Potassium	87
Mercury	NR	Praseodymium	0.3	Strontium	150	Chlorine	53
Gold		Cerium	2	Rubidium	≤ 0.1	Sulfur	>1000
Platinum		Lanthanum	2	Bromine	≤ 0.6	Phosphorus	91
Iridium		Barium	6	Selenium	9	Silicon	>1000
Osmium		Cesium		Arsenic	2	Aluminum	≥210
Rhenium		Iodine	0.7	Germanium	5	Magnesium	>1000
Tungsten		Tellurium		Gallium	0.3	Sodium	18
Tantalum		Antimony		Zinc	35	Fluorine	≈190
Hafnium		Tin		Copper	6	Oxygen	NR
Lutetium		Indium	STD	Nickel	29	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	3	Carbon	NR
Thulium		Silver	0.9	Iron	< 1000	Boron	0.5
Erbium		Palladium		Manganese	22	Beryllium	
Holmium		Rhodium		Chromium	1	Lithium	0.6
Dysprosium						Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

TABLE A-14. SSMS ANALYSIS OF LIME SCRUBBING END PRODUCT WITH WEP PRESCRUBBER IN USE (SAMPLE NO. M-098)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	≤2	Terbium		Ruthenium		Vanadium	7
Thorium		Gadolinium		Molybdenum	2	Titanium	50
Bismuth		Europium		Niobium	≤ 0.4	Scandium	≤ 0.2
Lead	1	Samarium		Zirconium	3	Calcium	1000
Thallium		Neodymium	0.8	Yttrium	5	Potassium	87
Mercury	NR	Praseodymium	0.3	Strontium	150	Chlorine	80
Gold		Cerium	2	Rubidium	≤ 0.1	Sulfur	> 1000
Platinum		Lanthanum	1	Bromine	≤ 1	Phosphorus	91
Iridium		Barium	6	Selenium	9	Silicon	> 1000
Osmium		Cesium		Arsenic	3	Aluminum	≥ 210
Rhenium		Iodine		Germanium	3	Magnesium	> 1000
Tungsten		Tellurium		Gallium	0.5	Sodium	27
Tantalum		Antimony		Zinc	35	Fluorine	≈ 250
Hafnium		Tin		Copper	7	Oxygen	NR
Lutetium		Indium	STD	Nickel	9	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	3	Carbon	NR
Thulium		Silver	0.6	Iron	> 1000	Boron	4
Erbium		Palladium		Manganese	36	Beryllium	
Holmium		Rhodium		Chromium	2	Lithium	0.7
Dysprosium						Hydrogen	NR

NR - Not Reported
All elements not detected <0.3 ppm weight
INT - Interference *Heterogeneous

APPENDIX B

BAGHOUSE TESTING AT MOLYCORP'S WASHINGTON, PA MOLYBDENUM ROASTING FACILITY

SECTION 1

BACKGROUND

In June of 1978, tests were conducted at Molycorp, Inc. to characterize the off gas treatment system of their molybdenum roaster. When the data was worked up it was found that the baghouse was not performing as well as expected. Baghouses normally remove 99+% of the particulate matter, while the baghouse at Molycorp was operating in the 88% removal range. The cause of this problem was found to be several broken bags in the baghouse.

In September of 1979, the efficiency of the baghouse was retested with all of the bags inspected before sampling. The sampling was performed on September 15 and 16. Three grain loadings were determined at the inlet and outlet of the baghouse using in-stack filtration methods (EPA Method 17). Because of the high grain loading at the inlet, a 30 x 100 mm glass fiber thimble was used for particulate collection. This allows for a longer period of sampling because of the large surface area of the thimble. At the outlet of the baghouse, a 47 mm round glass fiber thimble was used.

In addition to grain loading data, an attempt was made to determine vapor phase elemental concentrations at the inlet and outlet of the baghouse. These would consist of everything that condensed in the glass lined probe and impinger train following filtration at the stack temperature.

SECTION 2

SUMMARY OF RESULTS

The following results were obtained from the three simultaneous runs at the inlet and outlet of the baghouse:

	Baghouse Inlet			Baghouse Outlet		
Run #	1	2	3	1	2	3
Temperature °F	710	737	748	387	393	397
H_2O %	5.84	5.74	4.63	3.00	2.41	3.28
Velocity ft/sec	62.5	64.5	65.4	46.4	49.7	52.7
Flow Rate DSCFM	5650	5750	5850	11400	12300	12900
Particulate Conc. Grain/DSCF	4.19	4.27	5.06	.064	.029	.026
Particulate Mass. Rate lb/hr	203	211	254	6.21	3.03	2.88

The average grain loading at the inlet was 4.51 grains/DSCF while the average outlet grain loading was 0.040 grains/DSCF. This is a removal rate of 99.1% on a concentration basis. On a mass basis, an average of 223 lbs/hr of particulate went into the baghouse while an average of 4.04 lbs/hr exited the baghouse for a removal efficiency of 98.2%.

The temperature and flow rate of the gas at both the inlet and outlet ducts were increasing throughout the sampling period. A complete listing of all the stack data collected may be found in Section 4 of the report.

SECTION 3

SAMPLING TECHNIQUES

To meet the requirements of the testing program, several different types of sampling were conducted. The various sampling methodologies are described below. In most cases standard methods were applied. Where variations from standard procedures were used, the departures are outlined.

3.1 Gases

Volume Flow Rates

Gas stream velocities were measured with standard "S-type" pitots. Pressure differentials were read with magnehelic gauges. Temperatures were determined with chromel-alumel thermocouples using digital temperature indicator read-outs. Atmospheric pressure was determined with an aneroid barometer. Velocities and volumetric flow rates were calculated using EPA reference methods 1 and 2.

Gas Analysis for Dry Molecular Weight

To determine dry molecular weight of the gas stream, grab samples were taken in aluminized Teflon® bags. Samples were analyzed on a Burrel Orsat Analyzer. This gives O_2 + CO_2, N_2 was determined by difference.

Moisture Content

Moisture Content of the gas streams was determined by the condensation weight method (EPA Method 4). A metered volume of gas is drawn through a series of impingers, the last containing silica gel. The impingers are immersed in an ice bath. The impinger weight gain minus the weight of sorbed SO_2 and SO_3 represents the water content of the sample volume. The volume percent is then calculated.

Particulates

Grain Loading

Grain loadings were determined using EPA reference method 17. Method 17 uses an in-stack filter at duct temperature. Method 17 was used at both the inlet and outlet ducts of the baghouse.

SECTION 4

SOURCE SAMPLING RESULTS

The data and results of the source sampling are provided in the following tables B-1 through B-18.

TABLE B-1

SOURCE SAMPLING FIELD DATA
INPUT VERIFICATION

PLANT NAME MOLYCORP
SAMPLING LOCATION BAGHOUSE INLET — SAMPLE IDENT. IGL-1
DATE 9/15/79 (MMDDYY) — TIME START 17:55 (HHMM) — TIME FINISH 18:19 (HHMM)
DIAMETER 2. FT.
PTCF .84 — DGMCF 1.036
NOZZLE DIA. .250 INCHES
BAR PRESS 29.01 "HG
STATIC PRESS. -3.9 "H20 .0
INITIAL LEAK RATE .000 CFM
FINAL LEAK RATE .000 CFM
OPERATOR INITIALS KWL

TEST DURATION 24. MIN.
% CO .0 — % N2 81.7
% CO2 2.2 — % H2 .0
% O2 16.1 — % CH4 .0
CONDENSED WATER 18.0 GMS
FILTER WT. GAIN 3.71600 GMS
PROBE WASH WT. GAIN .01570 GMS

PT.	CLOCK TIME	DRY GAS METER READING	DP IN. H20	DH IN. H20	STACK TEMP. (F)	DRY GAS METER TEMPERATURE INLET (F)	DRY GAS METER TEMPERATURE OUTLET (F)	HOT BOX TEMP. (F)	LAST IMPINGER TEMP. (F)	L. VAC. IN. HG GAUGE
1	1755.	820.861	.53	1.06	712.	74.	75.	280.	0.	5.0
2	1757.	822.000	.56	1.12	703.	88.	76.	280.	0.	5.0
3	1759.	.000	.60	1.20	709.	93.	76.	280.	0.	6.0
4	1801.	.000	.59	1.18	714.	96.	78.	280.	0.	6.0
5	1803.	.000	.56	1.12	716.	101.	79.	280.	0.	6.0
6	1805.	.000	.54	1.08	706.	106.	81.	280.	0.	6.0
7	1807.	828.300	.55	1.10	708.	108.	81.	280.	0.	6.0
8	1809.	829.700	.58	1.16	713.	110.	82.	280.	0.	7.0
9	1811.	.000	.57	1.14	710.	113.	84.	280.	0.	8.0
10	1813.	832.000	.49	.98	710.	115.	85.	280.	0.	7.0
11	1815.	.000	.44	.88	710.	118.	86.	280.	0.	7.0
12	1817.	.000	.35	.70	710.	120.	88.	280.	0.	7.0
STOP	1819.	835.079								

REMARKS K'=20 1.2% SO2

TABLE B-2

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: IGL-1

PLANT NAME: MOLYCORP
SAMPLING LOCATION: BAGHOUSE INLET
DATE: 9/15/79 TIME START: 17:55 TIME FINISH: 18:19

REMARKS: K'=20 1.2% SO2

AVERAGE FLUE GAS TEMPERATURE	710.1	(F)	376.7	(C)
FLUE GAS PRESSURE (ABSOLUTE)	28.72	"HG	72.96	CMHG
FLUE GAS STATIC PRESSURE	-3.90	"H2O	-9.906	CMH2O
FLUE GAS MOLECULAR WEIGHT (WET)	28.35	LB/LB-MOLE	28.3535	GM/GM-MOLE
FLUE GAS PERCENT MOISTURE	5.84	%	5.84	%
AVERAGE FLUE GAS VELOCITY	62.5000	FPS	19.0500	M/S
AVERAGE FLUE GAS FLOWRATE	13869.	ACFM	393.	M3/MIN
	5655.	DSCFM	160.	M3/MIN
VOLUME OF FLUE GAS SAMPLED (DRY, STANDARD CONDITIONS)	13.7490	DSCF	.3894	M3
TEST DURATION	24.	MIN	24.	MIN
TEMPERATURE AT WHICH PARTICULATE COLLECTED	710.1	(F)	376.7	(C)
AVERAGE TEMPERATURE AT EXIT OF LAST IMPINGER/CONDENSER	.0	(F)	.0	(C)
MAXIMUM LINE VACUUM	8.0	"HG	20.32	CMHG
FINAL LEAK RATE	.000	CFM	.0000	M3/MIN
PERCENT ISOKINETIC	109.5	%	109.5	%
PARTICULATE MASS CONCENTRATION	.419E 01	GR/DSCF	.958E 01	GMS/M3
	.599E-03	LBS/DSCF		
PARTICULATE MASS RATE	.203E 03	LBS/HR	.921E 02	KG/HR

STANDARD CONDITIONS DEFINED AS 68 (F) & 29.92 "HG.

TABLE B-3

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: IGL-1

FLUE GAS VELOCITY/TEMPERATURE PROFILE

PT.	VELOCITY (FPS)	TEMPERATURE (F)
1	62.70	712.00
2	64.20	703.00
3	66.63	709.00
4	66.21	714.00
5	64.56	716.00
6	63.13	706.00
7	63.76	708.00
8	65.62	713.00
9	64.97	710.00
10	60.24	710.00
11	57.08	710.00
12	50.91	710.00
STOP		

TABLE B-4

SOURCE SAMPLING FIELD DATA
INPUT VERIFICATION

PLANT NAME MOLYCORP
SAMPLING LOCATION BAGHOUSE INLET SAMPLE IDENT. IGL-2T
DATE 9/16/79 (MMDDYY) TIME START 10:40 (HHMM) TIME FINISH 11:16 (HHMM)
DIAMETER 2. FT.
PTCF .84 DGMCF 1.036 TEST DURATION 36. MIN.
NOZZLE DIA. .250 INCHES % CO .0 % N2 81.7
BAR PRESS. 29.20 "HG % CO2 2.2 % H2 .0
STATIC PRESS. -3.9 "H2O .0 % O2 16.1 % CH4 .0
INITIAL LEAK RATE .000 CFM CONDENSED WATER 26.5 GMS
FINAL LEAK RATE .000 CFM FILTER WT. GAIN 5.70500 GMS
OPERATOR INITIALS KWL PROBE WASH WT. GAIN .00610 GMS

PT.	CLOCK TIME	DRY GAS METER READING	DP IN. H2O	DH IN. H2O	STACK TEMP. (F)	DRY GAS METER TEMPERATURE INLET (F)	DRY GAS METER TEMPERATURE OUTLET (F)	HOT BOX TEMP. (F)	LAST IMPINGER TEMP. (F)	L. VAC. IN. HG GAUGE
1	1040.	836.765	.53	1.06	734.	74.	74.	0.	0.	6.0
2	1043.	.000	.56	1.12	738.	84.	74.	0.	0.	6.0
3	1046.	840.000	.60	1.20	737.	92.	76.	0.	0.	6.0
4	1049.	842.000	.62	1.24	738.	98.	76.	0.	0.	7.0
5	1052.	843.800	.63	1.26	738.	102.	78.	0.	0.	7.5
6	1055.	846.000	.61	1.22	740.	106.	80.	0.	0.	8.0
7	1058.	847.600	.60	1.20	742.	110.	82.	0.	0.	8.5
8	1101.	849.200	.59	1.18	740.	114.	84.	0.	0.	9.0
9	1104.	651.400	.60	1.20	730.	116.	86.	0.	0.	9.3
10	1107.	853.600	.49	.98	735.	120.	89.	0.	0.	8.0
11	1110.	854.900	.44	.88	735.	122.	91.	0.	0.	8.0
12	1113.	856.500	.40	.80	735.	124.	94.	0.	0.	7.5
STOP	1116.	858.013								

REMARKS K=2.0 1.2% SO2

TABLE B-5

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: IGL-2T

PLANT NAME: MOLYCORP
SAMPLING LOCATION: BAGHOUSE INLET
DATE: 9/16/79 TIME START: 10:40 TIME FINISH: 11:16

REMARKS: K=2.0 1.2% SO2

AVERAGE FLUE GAS TEMPERATURE	736.8	(F)	391.5	(C)
FLUE GAS PRESSURE (ABSOLUTE)	28.91	"HG	73.44	CMHG
FLUE GAS STATIC PRESSURE	-3.90	"H2O	-9.906	CMH2O
FLUE GAS MOLECULAR WEIGHT (WET)	28.36	LB/LB-MOLE	28.3650	GM/GM-MOLE
FLUE GAS PERCENT MOISTURE	5.74	%	5.74	%
AVERAGE FLUE GAS VELOCITY	64.5154	FPS	19.6643	M/S
AVERAGE FLUE GAS FLOWRATE	14317.	ACFM	405	M3/MIN
	5751.	DSCFM	163.	M3/MIN
VOLUME OF FLUE GAS SAMPLED (DRY, STANDARD CONDITIONS)	20.6326	DSCF	.5843	M3
TEST DURATION	36.	MIN	36.	MIN
TEMPERATURE AT WHICH PARTICULATE COLLECTED	736.8	(F)	391.5	(C)
AVERAGE TEMPERATURE AT EXIT OF LAST IMPINGER/CONDENSER	.0	(F)	.0	(C)
MAXIMUM LINE VACUUM	9.3	"HG	23.62	CMHG
FINAL LEAK RATE	.000	CFM	.0000	M3/MIN
PERCENT ISOKINETIC	107.7	%	107.7	%
PARTICULATE MASS CONCENTRATION	.427E 01	GR/DSCF	.977E 01	GMS/M3
	.610E-03	LBS/DSCF		
PARTICULATE MASS RATE	.211E 03	LBS/HR	.955E 02	KG/HR

STANDARD CONDITIONS DEFINED AS 68 (F) & 29.92 "HG.

TABLE B-6

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: IGL-2T

FLUE GAS VELOCITY/TEMPERATURE PROFILE

PT.	VELOCITY (FPS)	TEMPERATURE (F)
1	63.06	734.00
2	64.93	738.00
3	67.18	737.00
4	68.32	738.00
5	68.87	738.00
6	67.83	740.00
7	67.32	742.00
8	66.71	740.00
9	66.99	730.00
10	60.66	735.00
11	57.49	735.00
12	54.81	735.00
STOP		

TABLE B-7

SOURCE SAMPLING FIELD DATA
INPUT VERIFICATION

PLANT NAME MOLYCORP
SAMPLING LOCATION BAGHOUSE INLET SAMPLE IDENT. IGL-3
DATE 9/16/79 (MMDDYY) TIME START 14:42 (HHMM) TIME FINISH 15:18 (HHMM)
DIAMETER 2. FT.
PTCF .84 DGMCF 1.036 TEST DURATION 36. MIN.
NOZZLE DIA. .250 INCHES % CO .0 % N2 81.7
BAR PRESS. 29.20 "HG % CO2 2.2 % H2 .0
STATIC PRESS. -3.9 "H20 .0 % O2 16.1 % CH4 .0
INITIAL LEAK RATE .000 CFM CONDENSED WATER 21.5 GMS
FINAL LEAK RATE .000 CFM FILTER WT. GAIN 6.86900 GMS
OPERATOR INITIALS KWL PROBE WASH WT. GAIN .00490 GMS

PT.	CLOCK TIME	DRY GAS METER READING	DP IN. H20	DH IN. H20	STACK TEMP. (F)	DRY GAS METER TEMPERATURE INLET (F)	DRY GAS METER TEMPERATURE OUTLET (F)	HOT BOX TEMP. (F)	LAST IMPINGER TEMP. (F)	L. VAC. IN. HG GAUGE
1	1442.	859.302	.54	1.08	744.	78.	78.	0.	0.	3.0
2	1445.	861.100	.56	1.12	748.	92.	80.	0.	0.	3.5
3	1448.	863.000	.60	1.20	748.	100.	80.	0.	0.	4.2
4	1451.	864.600	.62	1.24	748.	106.	82.	0.	0.	5.0
5	1454.	866.500	.64	1.28	750.	110.	84.	0.	0.	6.0
6	1457.	868.500	.63	1.26	750.	114.	85.	0.	0.	6.0
7	1500.	840.400	.62	1.24	751.	118.	87.	0.	0.	6.0
8	1503.	872.300	.60	1.20	743.	121.	89.	0.	0.	6.5
9	1506.	874.200	.61	1.22	745.	124.	92.	0.	0.	6.5
10	1509.	876.000	.59	1.18	747.	127.	94.	0.	0.	7.0
11	1512.	878.000	.45	.90	748.	130.	98.	0.	0.	5.5
12	1515.	879.500	.37	.74	749.	132.	100.	0.	0.	5.0
STOP	1518.	881.148								

REMARKS K=2.0 1.2% SO2

TABLE B-8

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: IGL-3

PLANT NAME: MOLYCORP
SAMPLING LOCATION: BAGHOUSE INLET
DATE: 9/16/79 TIME START: 14:42 TIME FINISH: 15:18

REMARKS: K=2.0 1.2% SO2

AVERAGE FLUE GAS TEMPERATURE	747.6	(F)	397.5	(C)
FLUE GAS PRESSURE (ABSOLUTE)	28.91	"HG	73.44	CMHG
FLUE GAS STATIC PRESSURE	-3.90	"H2O	-9.906	CMH2O
FLUE GAS MOLECULAR WEIGHT (WET)	28.49	LB/LB-MOLE	28.4863	GM/GM-MOLE
FLUE GAS PERCENT MOISTURE	4.63	%	4.63	%
AVERAGE FLUE GAS VELOCITY	65.4100	FPS	19.9370	M/S
AVERAGE FLUE GAS FLOWRATE	14515.	ACFM	411.	M3/MIN
	5847.	DSCFM	166.	M3/MIN
VOLUME OF FLUE GAS SAMPLED (DRY, STANDARD CONDITIONS)	20.9698	DSCF	.5939	M3
TEST DURATION	36.	MIN	36.	MIN
TEMPERATURE AT WHICH PARTICULATE COLLECTED	747.6	(F)	397.5	(C)
AVERAGE TEMPERATURE AT EXIT OF LAST IMPINGER/CONDENSER	.0	(F)	.0	(C)
MAXIMUM LINE VACUUM	7.0	"HG	17.78	CMHG
FINAL LEAK RATE	.000	CFM	.0000	M3/MIN
PERCENT ISOKINETIC	107.6	%	107.6	%
PARTICULATE MASS CONCENTRATION	.506E 01	GR/DSCF	.116E 02	GMS/M3
	.723E-03	LBS/DSCF		
PARTICULATE MASS RATE	.254E 03	LBS/HR	.115E 03	KG/HR

STANDARD CONDITIONS DEFINED AS 68 (F) & 29.92 "HG.

TABLE B-9

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: IGL-3

FLUE GAS VELOCITY/TEMPERATURE PROFILE

PT.	VELOCITY (FPS)	TEMPERATURE (F)
1	63.79	744.00
2	65.07	748.00
3	67.35	748.00
4	68.46	748.00
5	69.62	750.00
6	69.07	750.00
7	68.55	751.00
8	67.21	743.00
9	67.82	745.00
10	66.76	747.00
11	58.33	748.00
12	52.91	749.00
STOP		

TABLE B-10

SOURCE SAMPLING FIELD DATA
INPUT VERIFICATION

PLANT NAME MOLYCORP
SAMPLING LOCATION BAGHOUSE OUTLET — SAMPLE IDENT. OGL1
DATE 9/15/79 (MMDDYY) — TIME START 17:50 (HHMM) — TIME FINISH 18:23 (HHMM)
DIAMETER 3. FT.
PTCF .84 — DGMCF .996 — TEST DURATION 33. MIN.
NOZZLE DIA. .242 INCHES — % CO .0 — % N2 80.9
BAR PRESS. 29.01 "HG — % CO2 1.3 — % H2 .0
STATIC PRESS. -4.9 "H20 .0 — % O2 17.8 — % CH4 .0
INITIAL LEAK RATE .010 CFM — CONDENSED WATER 11.5 GMS
FINAL LEAK RATE .010 CFM — FILTER WT. GAIN .04809 GMS
OPERATOR INITIALS KRW — PROBE WASH WT. GAIN .02450 GMS

PT.	CLOCK TIME	DRY GAS METER READING	DP IN. H20	DH IN. H20	STACK TEMP. (F)	DRY GAS METER TEMPERATURE INLET (F)	DRY GAS METER TEMPERATURE OUTLET (F)	HOT BOX TEMP. (F)	LAST IMPINGER TEMP. (F)	L. VAC. IN. HG GAUGE
1	1750.	443.280	.40	.96	386.	62.	60.	0.	0.	5.0
2	1753.	444.900	.49	1.17	387.	90.	60.	0.	0.	5.0
3	1756.	441.650	.50	1.20	387.	92.	60.	0.	0.	5.0
4	1759.	448.840	.49	1.18	387.	96.	61.	0.	0.	5.0
5	1602.	450.350	.50	1.20	387.	99.	62.	0.	0.	5.0
6	1605.	452.300	.50	1.20	385.	100.	64.	0.	0.	5.0
7	1608.	454.430	.45	1.08	384.	102.	64.	0.	0.	5.0
8	1611.	455.900	.42	.96	387.	102.	66.	0.	0.	5.0
9	1614.	457.780	.40	.96	387.	102.	64.	0.	0.	5.0
10	1617.	459.420	.25	.60	387.	101.	63.	0.	0.	5.0
11	1620.	460.770	.15	.00	387.	100.	62.	0.	0.	5.0
STOP	1623.	461.780								

REMARKS 1% SO2 K=2.4

TABLE B-11

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: OGL1

PLANT NAME: MOLYCORP
SAMPLING LOCATION: BAGHOUSE OUTLET
DATE: 9/15/79 TIME START: 17:50 TIME FINISH: 18:23

REMARKS: 1% SO2 K=2.4

AVERAGE FLUE GAS TEMPERATURE	386.5	(F)	196.9	(C)
FLUE GAS PRESSURE (ABSOLUTE)	28.65	"HG	72.77	CMHG
FLUE GAS STATIC PRESSURE	-4.90	"H2O	-12.446	CMH2O
FLUE GAS MOLECULAR WEIGHT (WET)	28.59	LB/LB-MOLE	28.5924	GM/GM-MOLE
FLUE GAS PERCENT MOISTURE	3.00	%	3.00	%
AVERAGE FLUE GAS VELOCITY	46.3881	FPS	14.1391	M/S
AVERAGE FLUE GAS FLOWRATE	19675.	ACFM	557.	M3/MIN
	11396.	DSCFM	323.	M3/MIN
VOLUME OF FLUE GAS SAMPLED (DRY, STANDARD CONDITIONS)	17.6267	DSCF	.4992	M3
TEST DURATION	33.	MIN	33.	MIN
TEMPERATURE AT WHICH PARTICULATE COLLECTED	386.5	(F)	196.9	(C)
AVERAGE TEMPERATURE AT EXIT OF LAST IMPINGER/CONDENSER	.0	(F)	.0	(C)
MAXIMUM LINE VACUUM	5.0	"HG	12.70	CMHG
FINAL LEAK RATE	.010	CFM	.0003	M3/MIN
PERCENT ISOKINETIC	103.3	%	103.3	%
PARTICULATE MASS CONCENTRATION	.636E-01	GR/DSCF	.145E 00	GMS/M3
	.908E-05	LBS/DSCF		
PARTICULATE MASS RATE	.621E 01	LBS/HR	.282E 01	KG/HR

STANDARD CONDITIONS DEFINED AS 68 (F) & 29.92 "HG.

TABLE B-12

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: OGL1

FLUE GAS VELOCITY/TEMPERATURE PROFILE

PT.	VELOCITY (FPS)	TEMPERATURE (F)
1	46.14	386.00
2	51.10	387.00
3	51.62	387.00
4	51.10	387.00
5	51.62	387.00
6	51.56	385.00
7	48.88	384.00
8	47.31	387.00
9	46.17	387.00
10	36.50	387.00
11	28.27	387.00
STOP		

TABLE B-13

SOURCE SAMPLING FIELD DATA
INPUT VERIFICATION

PLANT NAME MOLYCORP
SAMPLING LOCATION BAGHOUSE OUTLET SAMPLE IDENT. OGL-2
DATE 9/16/79 (MMDDYY) TIME START 10:40 (HHMM) TIME FINISH 11:16 (HHMM)
DIAMETER 3. FT.
PTCF .84 DGMCF .996
NOZZLE DIA. .242 INCHES
BAR PRESS. 29.20 "HG
STATIC PRESS. -4.9 "H20 .0
INITIAL LEAK RATE .000 CFM
FINAL LEAK RATE .000 CFM
OPERATOR INITIALS KRW

TEST DURATION 36. MIN.
% CO .0 % N2 80.9
% CO2 1.3 % H2 .0
% O2 17.8 % CH4 .0
CONDENSED WATER 10.4 GMS
FILTER WT. GAIN .02234 GMS
PROBE WASH WT. GAIN .01510 GMS

PT.	CLOCK TIME	DRY GAS METER READING	DP IN. H20	DH IN. H20	STACK TEMP. (F)	DRY GAS METER TEMPERATURE INLET (F)	DRY GAS METER TEMPERATURE OUTLET (F)	HOT BOX TEMP. (F)	LAST IMPINGER TEMP. (F)	L. VAC. IN. HG GAUGE
1	1040.	464.030	.50	1.20	393.	82.	70.	0.	0.	9.0
2	1043.	465.650	.50	1.20	393.	88.	71.	0.	0.	9.5
3	1046.	467.400	.49	1.20	393.	92.	71.	0.	0.	9.5
4	1049.	469.280	.50	1.20	393.	94.	71.	0.	0.	9.5
5	1152.	471.120	.49	1.20	393.	96.	71.	0.	0.	9.9
6	1155.	473.280	.50	1.20	393.	97.	72.	0.	0.	10.0
7	1158.	474.870	.52	1.25	393.	98.	71.	0.	0.	9.9
8	1601.	476.780	.50	1.20	393.	99.	72.	0.	0.	9.9
9	1604.	478.690	.50	1.20	394.	100.	75.	0.	0.	9.7
10	1607.	480.550	.45	1.08	393.	101.	76.	0.	0.	9.2
11	1610.	482.350	.35	.84	393.	101.	76.	0.	0.	8.8
12	1613.	484.960	.30	.48	393.	100.	74.	0.	0.	7.2
STOP	1616.	485.120								

REMARKS K=2.4 .7% SO2

TABLE B-14

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: OGL-2

PLANT NAME: MOLYCORP
SAMPLING LOCATION: BAGHOUSE OUTLET
DATE: 9/16/79 TIME START: 10:40 TIME FINISH: 11:16

REMARKS: K=2.4 .7% SO2

AVERAGE FLUE GAS TEMPERATURE	393.1	(F)	200.6	(C)
FLUE GAS PRESSURE (ABSOLUTE)	28.84	"HG	73.25	CMHG
FLUE GAS STATIC PRESSURE	-4.90	"H2O	-12.446	CMH2O
FLUE GAS MOLECULAR WEIGHT (WET)	28.66	LB/LB-MOLE	28.6572	GM/GM-MOLE
FLUE GAS PERCENT MOISTURE	2.41	%	2.41	%
AVERAGE FLUE GAS VELOCITY	49.6817	FPS	15.1430	M/S
AVERAGE FLUE GAS FLOWRATE	21071.	ACFM	597.	M3/MIN
	12266.	DSCFM	347.	M3/MIN
VOLUME OF FLUE GAS SAMPLED (DRY, STANDARD CONDITIONS)	20.0341	DSCF	.5674	M3
TEST DURATION	36.	MIN	36.	MIN
TEMPERATURE AT WHICH PARTICULATE COLLECTED	393.1	(F)	200.6	(C)
AVERAGE TEMPERATURE AT EXIT OF LAST IMPINGER/CONDENSER	.0	(F)	.0	(C)
MAXIMUM LINE VACUUM	10.0	"HG	25.40	CMHG
FINAL LEAK RATE	.000	CFM	.0000	M3/MIN
PERCENT ISOKINETIC	100.0	%	100.0	%
PARTICULATE MASS CONCENTRATION	.288E-01	GR/DSCF	.660E-01	GMS/M3
	.412E-05	LBS/DSCF		
PARTICULATE MASS RATE	.303E 01	LBS/HR	.138E 01	KG/HR

STANDARD CONDITIONS DEFINED AS 68 (F) & 29.92 "HG.

TYPING GUIDE SHEET

TABLE B-15

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: OGL-2

FLUE GAS VELOCITY/TEMPERATURE PROFILE

PT.	VELOCITY (FPS)	TEMPERATURE (F)
1	51.57	393.00
2	51.57	393.00
3	51.05	393.00
4	51.57	393.00
5	51.05	393.00
6	51.57	393.00
7	52.59	393.00
8	51.57	393.00
9	51.60	394.00
10	48.93	393.00
11	43.15	393.00
12	39.95	393.00
STOP		

TABLE B-16

SOURCE SAMPLING FIELD DATA
INPUT VERIFICATION

PLANT NAME MOLYCORP
SAMPLING LOCATION BAGHOUSE OUTLET — SAMPLE IDENT. OGL-3T
DATE 9/16/79 (MMDDYY) — TIME START 14:42 (HHMM) — TIME FINISH 15:18 (HHMM)
DIAMETER 3. FT.
PTCF .84 — DGMCF .996 — TEST DURATION 36. MIN.
NOZZLE DIA. .242 INCHES — % CO .0 — % N2 80.9
BAR PRESS. 29.20 "HG — % CO2 1.3 — % H2 .0
STATIC PRESS. -4.9 "H20 .0 — % O2 17.8 — % CH4 .0
INITIAL LEAK RATE .000 CFM — CONDENSED WATER 15.3 GMS
FINAL LEAK RATE .010 CFM — FILTER WT. GAIN .02269 GMS
OPERATOR INITIALS KRW — PROBE WASH WT. GAIN .01360 GMS

PT.	CLOCK TIME	DRY GAS METER READING	DP IN. H20	DH IN. H20	STACK TEMP. (F)	DRY GAS METER TEMPERATURE INLET (F)	DRY GAS METER TEMPERATURE OUTLET (F)	HOT BOX TEMP. (F)	LAST IMPINGER TEMP. (F)	L. VAC. IN. HG GAUGE
1	1442.	485.470	.55	1.32	397.	86.	74.	0.	0.	10.5
2	1445.	487.300	.50	1.20	397.	92.	74.	0.	0.	10.0
3	1448.	489.090	.50	1.20	397.	94.	76.	0.	0.	10.0
4	1451.	490.300	.55	1.32	397.	98.	76.	0.	0.	10.0
5	1454.	492.290	.55	1.32	397.	100.	78.	0.	0.	10.0
6	1457.	494.830	.55	1.32	397.	101.	78.	0.	0.	10.0
7	1500.	496.790	.60	1.44	397.	102.	80.	0.	0.	11.2
8	1503.	498.800	.60	1.44	398.	102.	80.	0.	0.	11.2
9	1506.	500.850	.50	1.20	397.	104.	80.	0.	0.	10.0
10	1509.	502.700	.45	1.08	397.	105.	80.	0.	0.	9.9
11	1512.	504.560	.45	1.08	397.	106.	82.	0.	0.	9.9
12	1515.	506.320	.45	1.08	397.	106.	82.	0.	0.	9.9
STOP	1518.	508.250								

REMARKS .7% SO2 K=2.4

TABLE B-17

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: OGL-3T

PLANT NAME: MOLYCORP
SAMPLING LOCATION: BAGHOUSE OUTLET
DATE: 9/16/79 TIME START: 14:42 TIME FINISH: 15:18

REMARKS: .7% SO2 K=2.4

AVERAGE FLUE GAS TEMPERATURE	397.1	(F)	202.8	(C)
FLUE GAS PRESSURE (ABSOLUTE)	28.84	"HG	73.25	CMHG
FLUE GAS STATIC PRESSURE	-4.90	"H2O	-12.446	CMH2O
FLUE GAS MOLECULAR WEIGHT (WET)	28.56	LB/LB-MOLE	28.5622	GM/GM-MOLE
FLUE GAS PERCENT MOISTURE	3.28	%	3.28	%
AVERAGE FLUE GAS VELOCITY	52.7830	FPS	16.0883	M/S
AVERAGE FLUE GAS FLOWRATE	22387.	ACFM	634.	M3/MIN
	12855.	DSCFM	364.	M3/MIN
VOLUME OF FLUE GAS SAMPLED (DRY, STANDARD CONDITIONS)	21.4534	DSCF	.6076	M3
TEST DURATION	36.	MIN	36.	MIN
TEMPERATURE AT WHICH PARTICULATE COLLECTED	397.1	(F)	202.8	(C)
AVERAGE TEMPERATURE AT EXIT OF LAST IMPINGER/CONDENSER	.0	(F)	.0	(C)
MAXIMUM LINE VACUUM	11.2	"HG	28.45	CMHG
FINAL LEAK RATE	.010	CFM	.0003	M3/MIN
PERCENT ISOKINETIC	102.2	%	102.2	%
PARTICULATE MASS CONCENTRATION	.261E-01	GR/DSCF	.597E-01	GMS/M3
	.373E-05	LBS/DSCF		
PARTICULATE MASS RATE	.288E 01	LBS/HR	.131E 01	KG/HR

STANDARD CONDITIONS DEFINED AS 68 (F) & 29.92 "HG.

TABLE B-18

SOURCE SAMPLING RESULTS SUMMARY
SAMPLE IDENT: OGL-3T

FLUE GAS VELOCITY/TEMPERATURE PROFILE

PT.	VELOCITY (FPS)	TEMPERATURE (F)
1	54.31	397.00
2	51.78	397.00
3	51.78	397.00
4	54.31	397.00
5	54.31	397.00
6	54.31	397.00
7	56.72	397.00
8	56.75	398.00
9	51.78	397.00
10	49.12	397.00
11	49.12	397.00
12	49.12	397.00
STOP		